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AN ASSESSMENT OF WET SYSTEMS FOR RESIDENTIAL REFUSE COLLECTION

Curran Associates, Incorporated

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The most promising wet system alternative is identified as a system using individual household grinders in low density areas, vacuum collection and neighborhood grinders in high density areas, dilute slurry transport of ground refuse in the existing sanitary sewer system, and joint treatment of refuse and sewage at an expanded treatment facility that includes anaerobic digestion for methane generation. However, the economic feasibility of even the most promising alternative is doubtful because of the high cost of grinding, and hydraulic transport of ground refuse in existing sewer systems may be feasible only if both metals and glass are excluded. A conventional collection of the nongrindable and bulky constituents of residential refuse will still be needed, albeit of a diminished frequency. The total 1973 cost of such a wet system is estimated at $113-$196 per household per year, of which $80-$105 is for grinding. This compares to a total cost for refuse and sewage collection and disposal under existing concepts of up to $115 per household per year. Projections for 1988 indicate that the wet system cost might rise to $130-$228, against a range of $61-$143 under conventional concepts. However, if the cost of the grinder is excluded (on the basis that individuals would purchase grinders for their convenience benefits), the 1973 wet system costs (to the public sector) would be only $33-$91, thus possibly less than existing public sector costs of about $43-$115 per household per year.

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AN ASSESSMENT OF WET SYSTEMS FOR RESIDENTIAL REFUSE COLLECTION:

Summary Report

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

This report presents a summary of research directed toward development of utilizing existing sanitary sewer systems to transport ground solid waste. Individual subcomponents were designed, tested, and the overall economic feasibility of this approach was determined.

A. W. Breidenbach, Ph.D.
Director
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Research Center, Cincinnati

ABSTRACT

This summary is a synopsis of a series of four technical reports evaluating the technical and economic feasibility of wet systems for residential refuse collection prepared by Curran Associates, Inc., under Contract 68-03-0183 to the EPA Solid Waste Research Laboratory, Cincinnati, Ohio.

The most promising wet system alternative is identified as a system using individual household grinders in low density areas, vacuum collection and neighborhood grinders in high density areas, dilute slurry transport of ground refuse in the existing sanitary sewer system, and joint treatment of refuse and sewage at an expanded treatment facility that includes anaerobic digestion for methane generation. However, the economic feasibility of even the most promising alternative is doubtful because of the high cost of grinding, and hydraulic transport of ground refuse in existing sewer systems may be feasible only if both metals and glass are excluded. A conventional collection of the nongrindable and bulky constituents of residential refuse will still be needed, albeit of a diminished frequency. The total 1973 cost of such a wet system is estimated at $113-196 per household per year, of which $80-$105 is for grinding. This compares to a total cost for refuse and sewage collection and disposal under existing concepts of up to $115 per household per year. Projections for 1988 indicate that the wet system cost might rise to $130-$228, against a range of $61-$143 under conventional concepts. However, if the cost of the grinder is excluded (on the basis that individuals would purchase grinders for their convenience benefits), the 1973 wet system costs (to the public sector) would be only $33-$91, thus possibly less than existing public sector costs of about $43-$115 per household per year.

CONTENTS

Page

Abstract iv

List of Figures vi

List of Tables vii

Acknowledgments viii

Sections

I Conclusions 1

II Recommendations 3

III Introduction 4

IV Grinding 9

V Collection and Disposal of Nongrindables 18

VI Hydraulic Transport 23

VII Treatment 30

VIII Sludge Handling 46

IX Environmental and Socioeconomic Impacts 63

X Total System Cost Analysis 79

XI Recommendations for Further Research 82

XII References 86

XIII Publications 92

FIGURES

No.		Page
1	Preliminary Design for a Household Grinder	10
2	Basement Installation of a Household Grinder	11
3	Limiting Refuse Concentrations for Hydraulic Transport in Sewers	26
4	Grinding Water Requirement	27
5	Existing Process Configuration at the Springfield Wastewater Treatment Plant	33
6	Planned Process Configuration at the Springfield Treatment Plant	35
7	Computer Model Representation of the Recommended Treatment Process Configuration for Ground Refuse	40
8	Dry Sludge Solids as a Function of Population Size and Refuse Generation	48
9	Flow Diagram of Sewage Treatment Plant Handling 100 gal/cap/day	49
10	Flow Diagram of Sewage Treatment Plant Handling 100 gal/cap/day plus 2.25 lb/cap/day	50
11	Sludge Handling, Alternative 1	54
12	Sludge Handling, Alternative 2	55
13	Sludge Handling, Alternative 3	56
14	Total Cost of Sludge Handling (Alternative 1, 2 and 3 as a Function of Population; for Average Refuse Generation Rate of 2.25 lb/cap/day	58

TABLES

No.		Page
1	Cost Estimates for Installations of Refuse Grinding System	13
2	Cost Comparisons Between the Foster-Miller and Meier-Nebiker Concepts	14
3	Estimated Rates of Flow and Strengths of Wastewater from All Contributors	34
4	Present and Projected Waste Concentrations	37
5	Seasonal Variations Due to Ground Refuse Addition	41
6	Treatment Costs for Sewage Alone; Planned Bondi Island Treatment Plant	43
7	Treatment Costs for Sewage Containing Ground Domestic Refuse	44
8	Total Cost of Sludge Handling (Alternative 1) in $/ton Dry Solids for Various Populations and Various Raw Refuse Generation Rates	59
9	Total Cost of Sludge Handling (Alternative 2) in $/ton Dry Solids for Various Populations and Various Raw Refuse Generation Rates	60
10	Total Cost of Sludge Handling (Alternative 3) in $/ton Dry Solids for Various Populations and Various Raw Refuse Generation Rates	61
11	Total Annual System Cost per Household Comparisons for Springfield	80

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The contribution to the study of a Review Panel was substantial, both in review of the early drafts of this report and in the opening of many interesting perspectives during the five discussion meetings held at periodic intervals in the course of this study. The panel members consisted of Mr. Donald Oberacker and Dr. Harry Bostian of the EPA National Environmental Research Center, Cincinnati, Ohio; Professor Bernard B. Berger, Director of the Massachusetts Water Resources Research Center; Dr. Roger Bolton, Professor of Economics at Williams College; Mr. Thomas G. Sanders, independent consultant and one of the initiators of research interest into Wet Systems for Refuse Collection; Dr. Donald D. Adrian, Professor of Civil Engineering, University of Massachusetts; Mr. Herbert B. Wyndham, Jr., Vice President, Malcolm Pirnie, Inc., New York; Mr. Adi Guzdar, Manager, Engineering Studies Division, Foster-Miller Associates, Waltham, Massachusetts; Dr. Iraj Zandi, Professor of Civil and Mechanical Engineering, University of Pennsylvania; and Mr. Wylie C. Hubbard, Superintendent of the Department of Public Works, City of Springfield, Massachusetts. Dr. Boyd Riley and Dr. Rudi Schmut, independent consultants, Mr. Al Fisk of Foster-Miller Associates, and Mr. Oscar Albrecht of the EPA National Environmental Research Center in Cincinnati also attended some of the panel meetings or gave substantial assistance.

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The authors benefited greatly from the comments and suggestions of the EPA Project Officers, Mr. Donald Oberacker and Dr. Harry Bostian, and the assistance of Mr. Robert Smith and Mr. Richard Eilers, also of the EPA National Environmental Research Center in Cincinnati, was invaluable in the development of the treatment plant computer model.

These many contributions notwithstanding, the responsibility for the accuracy and opinions expressed in this report is solely that of the writers.

SECTION I

CONCLUSIONS

The major conclusions of this case study can be summarized as follows:

1. Implementation of a wet system for residential refuse collection in the case study area of Springfield, Massachusetts, or any other urban area, is at least a decade distant.

2. The ability of existing gravity sewer systems to successfully transport the glass and ceramics fraction of refuse remains questionable. Maximum flow velocities encountered in many sewer systems are below the necessary scour velocities to prevent excessive deposition of ground refuse. Metals must definitely be excluded. The frequency of collection of non-grindables is likely to be higher than might be expected because of seasonal variations and the substantial quantities of bulky wastes not amenable to grinding. The adequacy of available grinding water without substantial additions of fresh water is also questionable.

3. To the extent that realistic cost estimates can be made in the face of the technical uncertainties that still exist in the Springfield, Massachusetts case study area would rise from $39 per year to $110-$140 per year under a wet systems implementation. However, if the cost of the grinder is excluded, costs to the public sector under the wet system might decrease to as low as $35-$40 per year.

   A consideration of national conditions is more favorable to the wet system, showing a total cost of $113-$196 per household per year, of which $80-$105 is for grinding. This compares to a total cost for refuse and sewage collection and disposal under existing concepts of up to $115 per household per year. Projections for 1988 indicate that the wet system cost might rise to $130-$228, against a range of $61-$143 under conventional concepts.

4. Given the premise of technical feasibility, any implementation that does occur is likely to be gradual, not unlike the spread of garbage grinders and trash compactors, and will depend on the development of a domestic grinder purchased by individual households at a cost consistent with consumer acceptance and its perceived domestic convenience benefits. Existing grinding concepts are not regarded as practically feasible.

5. Analysis of the socioeconomic impacts of a wet system implementation shows the resultant reduction of the refuse collection labor force in Springfield to be a minor problem, due to other employment opportunities within the public works sector and because of the gradual nature of system implementation.

6. The most important impacts of ground refuse additions on wastewater treatment facilities will be on preliminary, primary and sludge handling facilities. Conventional secondary and advanced waste treatment processes do not appear significantly affected. The major uncertainty relates to the possibility of introduction of toxic, nonbiodegradable compounds (mercury, chlorinated hydrocarbons, etc.).

7. The presence of numerous combined sewers in many urban areas, including the Springfield, Massachusetts case study area, is a serious barrier to the wet systems concept. This problem apart, our investigations show that an appropriately modified treatment facility can produce effluents of comparable quality to conventional effluents at plants treating only sewage.

8. The cost of dewatering and disposal of the sludge generated at a sewage treatment facility handling ground refuse is in the range of $15 to $25 per ton of dry solids, and substantially below that of a treatment facility handling only sewage solids. The major determinants of total per ton cost are per capita refuse generation rates and the number of persons served by the facility. Economies of scale and the predominance of a more readily dewaterable primary sludge are the major reasons for the relatively low unit costs. The sludge handling facilities of a plant handling an average residential refuse generation rate correspond to the size of the facilities handling only sewage sludge generated by 9 to 12 times the number of inhabitants.

SECTION II

RECOMMENDATIONS

The presently available factual evidence is still insufficient to make definitive judgments on the technical feasibility of the wet systems concept. This study has therefore identified and recommended a sequence of bench-scale investigations designed to resolve these uncertainties. Successful completion of the following studies, presented in order of priority, are regarded as prerequisites to further investments at a demonstration scale:

1. Study of hydraulic transport of ground refuse under unsteady flow and load conditions representative of sewer laterals in residential areas.

2. A field survey of refuse generation, water consumption and sewage generation to establish the daily correlation of refuse and sewage generation for individual households, a necessary prerequisite for the development of realistic grinder design specifications.

3. Evaluation of the wet systems concept from an energy consumption viewpoint.

4. Evaluation of potentially hazardous and non-treatable components in ground refuse - sewage mixtures, using advanced instrumentation methods on simulated treatment plant streams.

5. Development of alternative grinding concepts, including a laboratory study of mixing characteristics of refuse slurries and domestic sewage and actual construction and testing of a prototype grinder. The inability to develop a grinder within the cost limits established in the present study and the specifications developed under task 2 would be sufficient to abandon the concept as economically or technically unrealistic.

6. Re-evaluation of the economic and overall technical feasibility of the concept using the new information available from the above studies.

SECTION III

INTRODUCTION

The Concept of Wet Systems for Residential Refuse Collection

The wet system for residential refuse collection of prime interest to this research involves the use of the existing sewer system to transport domestic refuse from the individual home to the point of treatment and disposal, thereby eliminating conventional house-to-house collection by trucks. This idea depends on three technical prerequisites: the feasibility of reducing refuse in the home to a size suitable for hydraulic transport, the feasibility of transport of ground refuse in an existing sewer system without deleterious effects, and the feasibility of joint treatment of refuse and sewage at an existing or modified treatment plant. Implementation of the idea requires also economic feasibility, which demands that a rigorous cost-benefit analysis shows the proposed system to be economically favorable over other existing and proposed systems. Each of these prerequisites will be examined at some length in the sections that follow.

From the viewpoint of solid waste management, the major incentive for analyzing such a concept is the high cost of collection. The increasing costs are due primarily to an increase in per capita waste generation and an increase in labor wage rates. As noted by Clark,[1] the latter has been far in excess of inflationary trends as the increasing tendency for collective bargaining has had a substantial effect on the wage rates for individuals employed in local solid waste management functions. Although productivity of collection in the last decade has increased substantially, there are limits to further increases under the constraints of existing solid waste management concepts; substitutions of capital for labor can be accomplished only to the point of having a one-man crew on a truck so large it can no longer efficiently navigate the streets and, consequently, only basic changes to existing practice offer any hope to reduce the cost of solid waste collection.

Previous Research

The concept of wet systems for residential refuse collection has been previously studied by several university investigators and government funded research contractors. There is also a considerable body of research on pipeline systems for refuse transport that have as their prime focus not the collection of refuse, but the transportation of refuse from a few centrally located collection centers to the site of disposal. Much of this is directly applicable to the goals of this study.

Research on Wet Systems for Residential Refuse Collection. The first to investigate the feasibility of using sewers for refuse transport and joint refuse-sewage treatment was the Los Angeles County Sanitation

District, which conducted experiments with ground refuse in large interceptors in July 1963.[2] It was concluded that the idea was probably feasible, but not pursued further because of anticipated problems at the treatment plant, the most important of which being a projected 25-fold increase in sludge volume.

The next to study the idea was the ASCE Combined Sewer Separation Project. In a report published in February of 1968, the idea of including ground refuse in pressurized sewers was examined, but no experiments were conducted.[3] Independently in 1968, Nebiker and Meier[4] analyzed the idea from a social and environmental viewpoint, and they concluded on the basis of some preliminary cost/benefit estimates that the idea should be further pursued.

In 1970, Etzel[5] suggested the use of hydropulpers, widely used by the pulp and paper industry, as a means of refuse size reduction prior to discharge into the sewers. Etzel also suggested some radical changes at the sewage treatment plant, including the use of advanced waste treatment processes such as reverse osmosis to treat the high solids loadings that would result.

The first detailed research study was conducted by Foster-Miller under contract to EPA.[6] The objectives of this study were to evaluate the feasibility of hydraulic transport of ground refuse in existing sewer lines by experimentation in a section of straight sewer pipe, and to evaluate the feasibility of treating a sewage-refuse mixture at a conventional sewage treatment plant by laboratory analyses of sample refuse-sewage slurries. However, because the hydraulic experiments used water rather than sewage, and because limited treatment experiments were conducted, technical feasibility was not unequivocably demonstrated.[7] In a second phase, Foster-Miller developed a preliminary design for a household refuse grinder.[8] Experiments during this second phase showed that refuse was amenable to size reduction in small, low-powered slurry grinders and that the few components that were not easily ground constituted a relatively small weight and volume fraction of the total domestic refuse.

McKinney and Mahloch[9] examined the costs of the concept in late 1971 and concluded that at the present time, conventional collection was more economical. They stressed, however, that increased labor costs for refuse collection, improved wastewater treatment methods, and the successful development of grinders[10] would very likely make grinding and discharge to the sewers the preferred method.

In 1971, the Brookhaven National Laboratory[11] planned a three-year, $800,000 study for the Atomic Energy Commission to demonstrate the feasibility of the concept, followed by a $2.2 million study to investigate resource recovery at the treatment plant. The Brookhaven concept envisaged the use of neighborhood pulpers and transportation in sewers to a treatment plant which would recover paper fiber, glass, and metals and use pyrolytic treatment for the remaining constituents. The goal was an effluent of sufficient quality for aquifer-recharge. This planned project, however, was never funded.[12]

A second contract was let by EPA to Foster-Miller to study the feasibility of hydraulic transport of refuse in sewer appurtenances and other potential problem areas in sewer systems (siphons, manholes, T-junctions, bends, etc.).[13] Again, water rather than sewage was used as the transport medium. However, the results of this research did indicate some potential problems, and will be discussed further in later sections of this report.

Finally, in late 1972, Courtney and Sexton compared the sewer transport concept against pneumatic and pressurized alternatives. They concluded that sewer transport appeared particularly suitable for existing urban areas.[14]

Other Pertinent Research. The area of research that is most directly related to the wet system for refuse collection is that of pipeline transport of refuse. However, the emphasis has previously been on hydraulic transport from centrally located collection points to the ultimate disposal site, as an alternative to truck or rail haul, rather than eliminating house-to-house collection.

Of all the alternative pipeline systems considered to date, slurry transport has received most attention. This calls for refuse to be ground and mixed with sewage or water and conveyed under pressure as a slurry of between 6 and 12 percent solids content. However, several other pipeline concepts have been considered, including hydraulic transport of briquettes and slugs.[15]

The slurry pipeline idea has been pursued by Zandi and co-workers at the University of Pennsylvania for many years, and extended to include a vacuum system to bring refuse from the individual home to the neighborhood stations where the refuse is ground and injected into a slurry pipeline network.[16] This combination is therefore a direct competitor to the proposed system, in that it completely replaces conventional collection. Pipeline transportation of shredded solid waste was also investigated by researchers at the Western Company, who proposed the use of friction-reducing polymer additions to increase pipeline capacity.[17]

In the area of grinding, we must turn to recent developments in the pulp and paper industry, for the latest generation of hydropulpers appears to be eminently suited to the size reduction of paper-rich solid waste. The experience of the paper industry is also very important to an assessment of treatability. For many years it has worked in treating cellulose and fiber-rich wastes by technologies similar to sewage treatment, and with special emphasis on recovery.[18] In particular, screening is a technology well developed in the paper industry that is suitable as a modification to existing treatment plants for solids removal in preliminary treatment.

The feasibility of treating refuse slurries by technology adapted from the paper industry is currently under study at a demonstration project at Franklin, Ohio.[19] Designed by the Black Clawson Company for 150 tons of municipal refuse per day, the objective of the treatment plant is to recover metals, glass and paper. The first step in the treatment process is to pulp the incoming refuse in a hydropulper, using recycled process water and secondary effluents. Although a sewage-refuse slurry would require some substantial modifications in the treatment process configuration, the proposed system of wet collection of residential refuse appears to be entirely compatible with these latest efforts toward resource recovery from municipal solid wastes.

Detailed Technical Reports

The details of the technical, environmental and economic studies conducted under this contract have been published in four separate technical reports which are available from the National Technical Information Service, Springfield, Virginia 22151. The first report undertook a preliminary assessment of the economic and technical feasibility of the concept with a view to establishing the order of magnitude of costs involved and identifying the major areas of technical uncertainty.[20] A second report analyzed the economics of processing and disposal of refuse sludges, published separately in view of its possible interest to an audience not necessarily also interested in the wet systems concept.[21] The third report describes a detailed evaluation of the wet systems concept in the Springfield, Massachusetts Case study area to develop specific conclusions and cost estimates for the conditions encountered in an area typical of the Nation's urbanized regions.[22] And finally the fourth report documents the computer program developed for the assessment of treatment costs.[23] Again the motivation for a separate publication is the possible interest of the subject matter to an audience not necessarily interested in wet systems for residential refuse collection.

The Case Study Area

The choice of the Springfield Standard Metropolitan Statistical Area (SMSA) in Massachusetts as the case study area, and the city of Springfield as its major focus, is not dictated solely by its proximity to the contractor's home office and its representative size. Located in the picturesque Connecticut River Valley in western New England, considerable environmental awareness exists among its inhabitants, evidenced for example by its relatively advanced refuse recycling efforts. The SMSA has recently completed a planning program for both solid waste disposal and wastewater treatment and its wastewater treatment plant is in the process of being upgraded from primary to secondary treatment. Thus the case study addresses an area that is in a very active stage of environmental improvement, and thus displays an interest in the evaluation of innovative concepts. Indeed, the willingness of the city officials to assist the contractor in his investigations, especially the superintendent of the city's Department of Public Works and his deputies in charge of the refuse and sewer divisions, has been of valuable assistance. Moreover, Springfield exhibits many of the problems that must be addressed in a realistic evaluation of the concept, including the presence of a significant proportion of combined sewers and significant seasonal variations.

In retrospect, perhaps the major apparent disadvantage of the choice of Springfield as a case study area is the fact that the wet system implementation has had to be compared to an existing collection system of high cost-efficiency. But we have thereby avoided the pitfall of overestimating the benefits of a wet system implementation by comparison to an existing system that could easily be improved by other means. We recognize, of course, that there are undoubtedly areas of the country where many of the problems of a wet system encountered in Springfield do not exist or are of a much lesser magnitude. On the other hand, the most important consideration has been to ensure that all the important questions have been addressed, so that the research priorities that this study seeks to define have in fact been based on an evaluation of the the widest possible range of conditions.

SECTION IV

GRINDING*

Introduction

Although the original concept called for a refuse grinder in every residence, the existence of substantial economies of scale made a consideration of alternative grinding concepts potentially attractive. Grinders installed on a one-per-structure and one-per-block or neighborhood were examined, but rejected; the former because of serious questions as to ownership and maintenance responsibilities, the latter because of the very high cost of the vacuum collection system required to convey the refuse from the individual home to the central grinding station. Indeed, very high residential densities would be required to justify the block or neighborhood approach, densities found only in the older, central parts of urban areas where the practicability of installing vacuum systems in old housing was open to serious question (apart from also being those areas showing high incidence of combined sewers).

The investigations therefore returned to the one-per-residence approach, for which Foster-Miller had prepared a preliminary conceptual design.[24] An artist's impression of this design is shown on Figure 1. However, several questions arose as to the actual feasibility of the approach suggested by Foster-Miller, which centered on re-use of all domestic wastewater except that from water closets. This wastewater re-use would be attained by a plumbing separation feeding all non-fecal wastewater into a storage tank, the installation concept being shown on Figure 2.

First, because of power limitations, the grinding of ferrous metals at this scale was considered unrealistic. However, the exclusion of steel and heavy gauge aluminum was not judged a serious restriction, because it would be necessary anyway because of difficulties in hydraulic transport in gravity sewer systems. Because the design results in nongrindable materials staying within the grinder, and cleaned during the freshwater flushing cycle following a grinding, the metal nongrindables would be free of putrescible matter, and of relatively small volume; laboratory tests indicated that even tin cans would be considerably compressed. Storage until infrequent conventional collection would thus be feasible. Finally, the nongrindable metals would be clean (paper labels and paint would be removed during grinding, for example), and thus represent a much better raw material for metal recovery than raw refuse from which nonmetals must first be separated.

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*For more detailed discussions, see Meier, Kuhner and Martel, (Ref. 20), Chapter II and Meier, Kuhner and Bolton (Ref. 22), Chapter II.

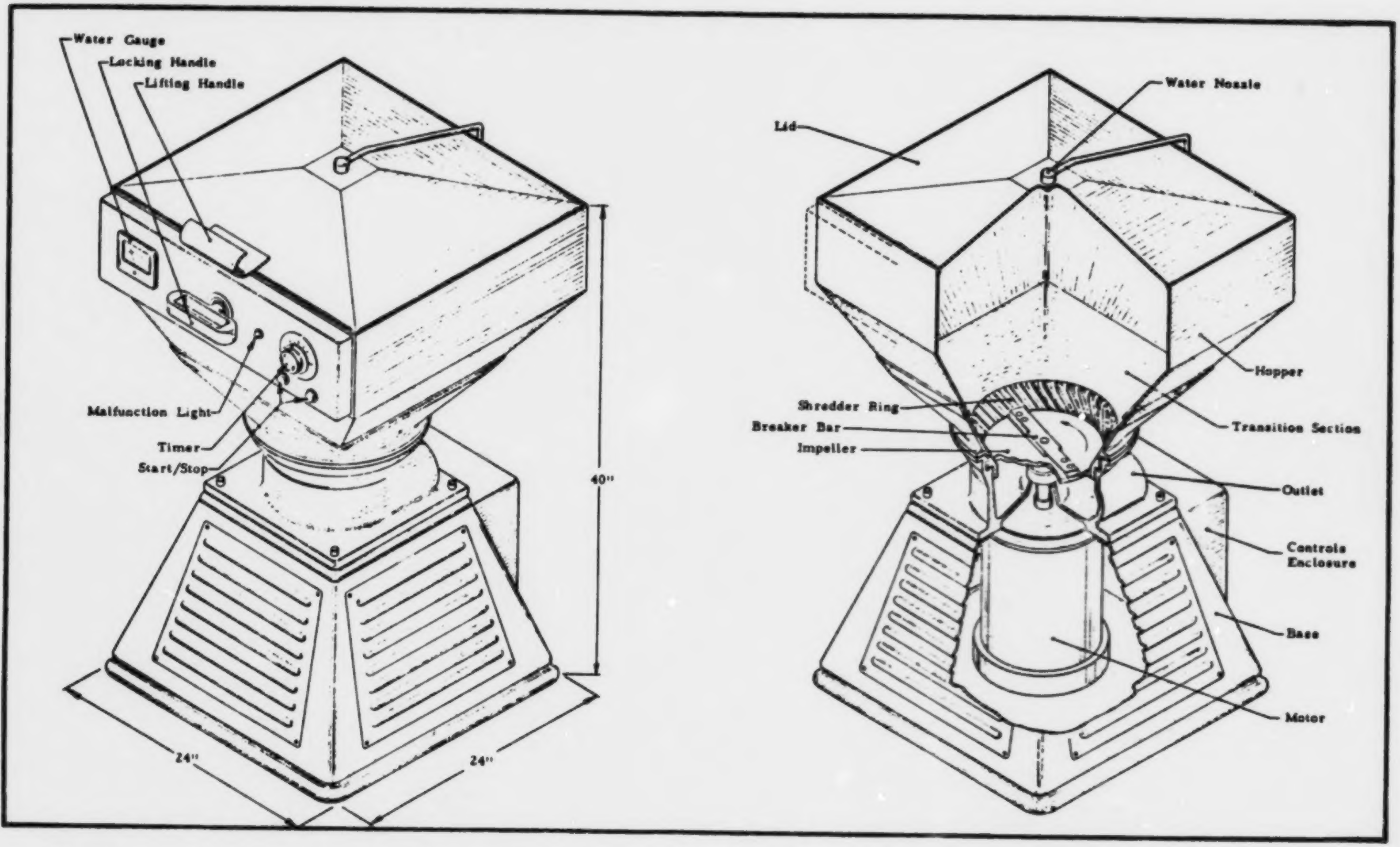
Water Gauge
Locking Handle
Lifting Handle
Malfunction Light
Timer
Start/Stop
40"
24"
24"
Water Nozzle
Lid
Hopper
Shredder Ring
Breaker Bar
Impeller
Transition Section
Outlet
Controls Enclosure
Base
Motor

Figure 1: Preliminary Design for a Household Grinder (Source: Fisk & Guzdar, op. cit., p. 83).

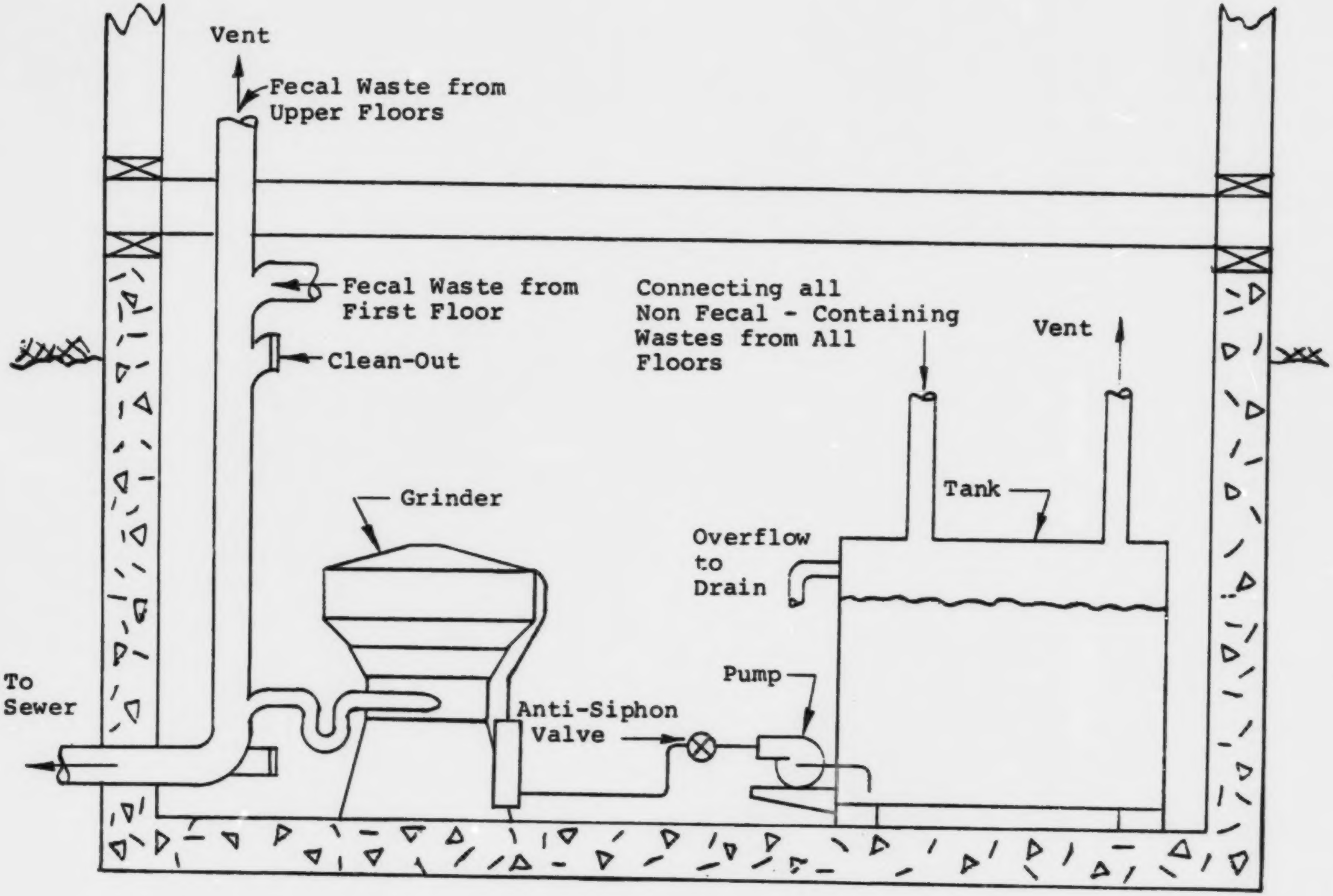
Vent
Fecal Waste from Upper Floors
Fecal Waste from First Floor
Clean-Out
Connecting all Non Fecal - Containing Wastes from All Floors
Vent
Tank
Grinder
Overflow to Drain
Pump
Anti-Siphon Valve
To Sewer

Figure 2: Basement Installation of a Household Grinder (Source: Fisk & Guzdar, op. cit., p. 32).

Second, the sufficiency of the quantity of reuseable wastewater necessary for grinding at a solids concentration at which no deleterious effects would occur during subsequent sewer transport (See below, Section VI), was found to be open to question. The subject is a complex one that did not lend itself to definitive resolution because of lack of data. However, the need to use some amount of fresh water, for either grinding or flushing (at the end of the grinding cycle) or both, was clear.

The most serious deficiency related to cost. Apart from the cost of the grinding unit itself, the cost of replumbing an existing residence to provide the grinding unit with its source of reused wastewater is prohibitive, as shown on Table 1. These costs were estimated by a plumbing contractor in the Springfield Case Study Area as bid price estimates, and are generally comparable, although about $200 higher, to the Foster-Miller estimates conducted two years previously. An alternative concept was also examined, whereby the grinding would occur at high consistency (say 5-10 percent refuse by weight), pumped to the sewer in a pressurized building connection, and relying on the flow already present in the sewer for dilution to the 0.5 to 1.0 precent concentration required for hydraulic transport. Grinding at high consistency would require less water for a given weight of refuse. However, the cost of the pressurized building connection, even though lower than under the wastewater reuse concept, was still found to be prohibitive. Table 2 shows an analysis of the cost of these two alternatives, which, at over $100 per household per year, completely outweigh all other costs of a wet system implementation.

For the purposes of further investigation, it was therefore concluded that some grinding concept would need to be developed that required neither a plumbing separation nor a pressurized building connection. But this still left open the question of the cost of the grinding unit itself, and the cost at which such an appliance might be considered a reasonable proposition.

The Refuse Grinder as a Domestic Appliance

The first approach in analysing a refuse grinder in terms of a domestic appliance is to study cost trends of similar household appliances; similar to a refuse grinder in either use, such as the garbage grinder; in consumer appeal, such as the refuse compactor; or in similarity to electromechanical sophistication and probable industrial production technique such as the automatic dishwasher. Unlike the washing machine, all three appliances still have connotations of convenience rather than necessity, and, also unlike washing machines, are many years from market saturation.

An analysis of the trends in price of these appliances over the last twenty years shows dramatic decreases; not only decreases in terms of inflation adjusted dollars but even in terms of actual selling prices.

Table 1: Cost Estimates for Installations of Refuse Grinding System

Construction Type	Estimated Total Cost
New Construction 2 Story Slab	$ 500.00 - 550.00
New Construction 2 Story Basement	550.00 - 600.00
New Construction 1 Story Slab	400.00 - 450.00
New Construction 1 Story Basement	450.00 - 500.00
Old Construction 2 Story Slab	1300.00 -1400.00
Included in above:	
Excavating concrete floor and patching	150.00
Excavating pit and concrete fill	300.00
Cut and patch and paint walls	175.00
Remove and relay carpets	75.00
Old Construction 2 Story Basement	925.00 -1025.00
Included in above:	
Excavating concrete floor and patching	75.00
Cut and patch and paint walls	175.00
Old Construction 1 Story Slab	1100.00 -1200.00
Included in above:	
Excavating concrete floor and patching	150.00
Excavating pit and concrete fill	300.00
Cut, patch and paint walls	100.00
Remove and relay carpets	75.00
Old Construction 1 Story Basement	725.00 - 825.00
Included in above:	
Excavating concrete floor and patch	75.00
Cut, patch and paint walls	$ 100.00

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Table 2: Cost Comparisons Between the Foster-Miller and Meier-Nebiker Concepts

		Foster-Miller (Grinding at 1% Solids with Wastewater Reuse)		Meier-Nebiker (Grinding at 7% Solids Discharge via Pressurized Building Connection)	
Item	Assumed Life	Cost	Annual Cost at i = 6%	Cost	Annual Cost at i = 6%
Grinder	15	$180	$18.50	$200	$20.60
Installation	15	75	7.70	75	7.70
Distr. and Sales Costs	15	191	19.65	191	19.65
Storage Tank	30	116	8.40	0	0
Installation	30	75	5.40	0	0
Distr. and Sales Costs	30	143	10.40	0	0
Building Connection	30	0	0	450-500	32.60-36.30
Plumbing Modification	30	520-1,050	37.75-76.20	0	0
Total Initial Costs		1,300-1,830	108-146	916-966	80-84
Water			1.50		3.00
Power			2.50		2.50
Repairs			16.00		16.00
Total Annual Cost			128-166		101-105

For example, in 1952, the automatic dishwasher rated best by Consumer Reports cost $354; in 1969, the cost had decreased to $280, a decrease of $74.[25] If one adjusts for inflation, say by use of the consumer price index, the decrease in real cost was $210. Similar decreases were established for the other appliances mentioned above.

The conclusion from such a comparison is that the initial selling price of a newly introduced appliance will fall (if not in current dollars, certainly in inflation adjusted dollars), and that whatever the initial cost that might be hypothesized, this would fall as manufacturing refinements, competition and economies of scale become operative with increasing production levels.

The Appliance Industry Viewpoint. In view of the aforementioned similarities between the refuse grinder, the trash compactor, and other similar appliances, a discussion of the appliance industry viewpoint on compactor sales is clearly pertinent to an assessment of the prospects of a refuse grinder. The appliance industry sees trash compactors as an item having strong growth potential in the upcoming years. The trash compactor is the first new major domestic appliance in years, having been introduced only in 1970, and is therefore felt to have "novelty value." In reply to critics of the trash compactors' comparatively low sales volume, it is often pointed out that it took dishwashers many years, literally decades, to become the strong selling item they presently are.

The existing price level of around $200 is felt to be a strong selling point. This is considered low, and the prospects for even lower prices, as previously documented, are good. It is also noted that despite hindered consumer appeal of dishwashers at the time, some 15 years ago, that their price was in excess of $300, sales did ultimately accelerate as price decreases became possible. Indeed, one can identify a psychological barrier at a retail sales price of around $300, and any major appliance selling for less is considered likely to gain broad consumer appeal.

In view of the presently identifiable market for trash compactors, namely residents of relatively high-income, suburban single-family home areas, speciality advertising that has maximum impact on sales is regarded as very effective. Retailers are pressing the manufacturers for additional advertising in this direction. And yet another perceived advantage is the feeling that because ecology and the environment will become of increasing concern to the householder, advertising can make the compactor appear to have a strong positive affect on the environment - thus appealing to the "environmentally conscious" consumer.

Implications for the Refuse Grinder. Whatever the shortcomings of the industry viewpoint toward trash compactors, and especially with regard to its exaggerated environmental benefits, it must nevertheless be concluded that some degree of consumer acceptance already exists, and that this is likely to grow.

Unquestionably, a refuse grinder would offer much greater convenience benefits than the compactor. Since refuse would be ground daily, there would not be the odor problem that characterises compactors. The special bags that are required for the compactors would no longer need to be purchased, nor would the compacted refuse need to be carried to the point of pickup, a task, incidentally, that because of the high density of the compacted product, would certainly be beyond the many persons unable to carry heavy loads.

There would of course be some relative disadvantages over the compactor, including that of higher noise levels and the need to periodically remove nongrindables. Nevertheless, it does not appear unreasonable to suggest that consumer acceptance of an appliance offering unquestionably greater convenience benefits would be almost assured at an initial price of somewhat less than $300, falling gradually as sales increase to perhaps a level of around $200.

One aspect that must be stressed, however, is the need for operational reliability if consumer acceptance is to be gained. As an appliance that might require housecalls by either plumbers or electricians in the event of malfunction, the potentially high cost of repairs might prove to be a substantial deterrent, even to the relatively affluent suburban resident.

Conclusions

If the similarities of the refuse grinder to the garbage grinder, automatic dishwasher, and trash compactor are indeed valid, several conclusions can be drawn from the analysis of recent cost trends.

1. A refuse grinder selling at less than $300.00 would gain consumer acceptance.
2. The cost of the grinder should decrease in the first few years of production because of design improvements, economies of scale and competition.
3. The real cost (inflation adjusted) of the refuse grinder should at worst remain stable, but probably decrease with time.

The conclusions with respect to the feasibility of the wastewater reuse concept appear quite unfavorable. The cost of replumbing existing housing units is clearly prohibitive, and it is even questionable whether the additional plumbing costs in new housing would be acceptable. Although such costs might well be included in the total purchase price, and hence buried in the mortgage payments, the high interest costs thereby incurred have considerable bearing on the real social cost of the wet systems concept.

The presently ascertainable costs of grinding have some very interesting consequences for judging the most likely initial wet systems implementation. Because of their high cost, grinders would inevitably find their first purchasers in the relatively affluent suburbs for installation in single-family homes of low residential density. Moreover, such areas are very often characterised by very high conventional collection costs because the low costs of an efficient municipal house-to-house service are not available at such low densities. Many suburban residents spend $1 to $2 a week for a private refuse pick-up, and consequently there may be a real economic benefit in addition to the convenience benefits. This motivation exists far less in the central urban areas where municipal collection, as for example in the Springfield Case Study Area, may cost as little as $12.00 per household per year. It could of course be argued that scale economies of grinding could be exploited in central urban areas by virtue of the possibility of a one-per-structure or a one-per-neighborhood installation of grinders, as noted previously. However, again by reference to the case study area, almost 70 percent of the housing units in Springfield are single-family or duplex residences, for which only one-per-living unit installation is feasible; and in those areas where the housing density is sufficient for, say, neighborhood grinders, the presence of combined sewers makes the concept inoperable.

All the preceding assumes that a grinding concept can be developed that does not require replumbing or a pressurized building connection, yet it is clear that the details of such a concept have yet to be researched. In the absence of such concepts, we may conclude that installation of existing grinding concepts in single-family or duplex housing is economically infeasible. The necessity for further research in this area is obvious, and is again addressed in the concluding section.

One alternative that might lessen the impact on the home owner is that of public or quasi-public rather than private ownership. In a manner similar to the leasing of hot water heaters from electric utilities (common in New England), so might refuse grinders be leased from a municipal refuse utility. This utility would also be responsible for maintenance, and could readily arrange for emergency conventional collection during grinder breakdowns. Indeed, in areas of multi-family housing where ownership and maintenance responsibilities are defined only with difficulty, such an arrangement appears mandatory. However, as so eloquently argued by Foster-Miller in their preliminary grinder design report, it is unlikely that anything less than private ownership would engender sufficient respect for the appliance, which in contrast to hotwater heaters, will require continuous care and attention if frequent breakdowns are to be avoided. But again, even definition of the utility concept depends first on the development of a grinding concept of reasonable total cost.

SECTION V

COLLECTION AND DISPOSAL OF NONGRINDABLES*

Introduction

Although the intent of the wet systems for residential refuse collection is to eliminate conventional collection methods, it is readily apparent that some residual conventional collection will still be necessary, albeit of a drastically reduced scope. Even if grinders were to be capable of handling metals, large bulky items would still need removal. Moreover, many other small constituents in residential refuse are not amenable to grinding in the small grinders of single homes, especially resiliant plastics, rubber, leather and some synthetic textiles.

But the conventional collection and subsequent disposal of only the nongrindable constituents will bring some major changes to existing solid waste management practice. Volume will be markedly reduced, and density markedly increased as the light, bulky constituents (paper, food packaging, garbage) are easily ground. The frequency of collection may be very low, but acceptable, because all putrescible materials will be ground. The increased density and weight of standard containers would require trucks to be fitted with hydraulic lifts for the much heavier full containers, and may demand that all containers be picked up from a rear-house rather than curbside location. Calculations developed elsewhere suggest that the density of nongrindables may be up to 50 percent higher than the density of uncompacted raw refuse.[26] Changes in truck design to allow for the more difficult compaction of the collected material and the increased axle load would also be necessary; indeed, the compactor trucks widely used today may be quite inappropriate under the proposed system. A major impact of a wet systems implementation would of course be a dramatic decrease of the collection labor force. The socioeconomic consequences of such a decrease are considered in detail in Section IX, below; but were found to be much less serious than might at first appear, especially with respect to layoffs.

Quantity of Nongrindables in the Case Study Area:

The 1972 city-wide average domestic refuse generation rate for Springfield was established as 2.56 lb/cap/day,[27] broken down as follows:

Bulky refuse, collected by appointment	0.07 lb/cap/day
Separately collected garbage	0.11
Garbage now ground to sewer	0.11

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[*] See Meier, Kuhner and Bolton, Ref. 22), Chapter III for details relative to the case study area, and Meier, Kuhner and Martel, (Ref.20) Chapter VI for a general discussion of the relationships involved.

Separately collected newspaper	0.01
All other components (regular collection)	2.26
	2.56 lb/cap/day

However, these averages were shown to hide considerable quantity variation, both by season and by route, and also considerable variation in composition. But no data other than an occasional sampling or our brief survey were available. Moreover, the figures also include an undetermined amount of commercial refuse from a downtown collection on Friday evenings. Exact calculations to derive the quantity and components of refuse ground, and not ground, were therefore very difficult because of lack of appropriate data. The calculations developed to measure the impact on wastewater treatment facilities were therefore based on the assumption that of the 2.56 lb/cap/day, 10 percent or 0.256 lb/cap/day was nongrindable (based on doubling the amount of bulky refuse, as noted below, plus continued separate collection of newspaper, plus about 4 percent of nonbulky heavy metals, hence: 0.07 + 0.07 + 0.01 + 0.106 = 0.256). To the extent that glass, ceramics and light metals would not be ground, the weight percentage of nongrindables would be substantially higher.

It should perhaps also be noted that the 2.56 lb/cap/day residential refuse generation rate for Springfield is consistent with a national average of 2.25 lb/cap/day, as established on the basis of the latest data from the EPA Data Aquisition and Analysis System for Solid Waste Collection.[28]

Seasonal Peaks. Substantial seasonal peaks, and especially the fall peak of garden wastes in areas such as New England as typified by the case study area, will have an important impact on the final design of a wet systems implementation. If one assumes that the peaks are composed of largely grindable material, as would be the case for the fall peak, then the treatment plant would need to be able to handle load fluctuations much higher than otherwise necessary. Moreover, substantial quantities of fresh water would be necessary to augment the normally available grinding water supply, which in turn might impose significant demands on the water system. On the other hand, if the peaks are composed of largely nongrindable materials, as would be the case in spring, at which time relatively bulky attic wastes appear to be the major component, a regular schedule of nongrindable collection (based on a more or less constant generation rate of nongrindable residuals) would be substantially disrupted by strong peaks. Indeed, aperiodicity in nongrindable collection might follow unless additional storage space is available. Perhaps compactors might continue to play an important role here, as the operational complexities of aperiodic collection schedules are formidable.

Bulky Wastes. The problem of bulky wastes was also found to be much greater than originally anticipated, because one must expect that a significant fraction of the bulky wastes now collected by the regular collection could not be ground by virtue of its bulk (rather than by virtue of its composition). The majority of the bulky waste appears to be of such a size that it can be included in a normal container, or is picked up by the collection crews as a matter of habit (if not as a matter of regulation); and thus the existing bulky item collection is reserved primarily only for the exceptionally heavy or bulky material. But small furniture, large plastic toys, small appliances, and the like, would not be readily grindable, and thus the demand for bulky item collection would undoubtably increase under a wet systems implementation. At the very minimum, a doubling of the bulky item collection might be expected.

Unfortunately, we have only our qualitative observations taken during the route surveys in the case study area to support this contention, and quantitative data is needed before a more exact judgment can be made. We shall return to this point in our recommendations for further research.

Commercial Establishments. With regard to the case study area, the city of Springfield seems to feel very strongly about providing solid waste collection service to commercial establishments, as evidenced by the city's willingness to pickup commercial refuse on residential routes without charge. It seems reasonable to assume, therefore, that the city would also be willing to let such commercial establishments install grinders, to the extent that the nature of their refuse would be compatible with sewer transport. Because the collection of nongrindables would be infrequent, inclusion of commercial establishments in the latter collection would not replace the need for regular weekly collection of commercial refuse were grinding not allowed.

If commercial establishments were allowed to use refuse grinders, rigorous enforcement of ordinances specifying prohibited materials would be necessary. A permit granted only after analysis of a commercial establishment's refuse, with the permit fee applied to the cost of sampling and analysis of the refuse, might be one way of regulation. Because the new water quality legislation requires those who add industrial wastes to the sewerage system to pay an equitable portion of treatment costs, it is probable that commercial establishments would likewise need to pay some form of user charge. Grinders at most commercial establishments would obviously depend entirely on fresh water for grinding water, and hence metering of the freshwater inflow to the grinder could be used for an equitable user charge since the quantity of water used will be proportional to the weight of refuse ground and introduced to the sewer.

Emergency Collection. An important consideration in assessing the acceptability of the wet systems concept is that of its flexibility to accomodate failures. The capital intensity of the wet system would appear at first glance to compare poorly with the existing system whose labor-intensity and the possibility of incentive and overtime schemes makes it relatively easy to handle unforeseen refuse peaks or equipment failures; witness for example, the existing arrangements in Springfield where crews who have finished early are assigned to other routes in cases of breakdown or exceptional peaks.

There are two sources of potential failure of the wet system. The first is that of grinder breakdown, and clearly an emergency collection, available on demand, would need to be available for such situations. However, some form of incentive would be necessary to expedite repair of the grinding equipment, and a nominal pick-up fee imposed after one or two weeks of emergency collection might be appropriate.

The second, and potentially more serious problem, would follow a sewer blockage. If a sewer blockage did occur, some mechanism would be necessary to inform upstream residents to cease use of their grinders until repairs were complete, as the continued load of refuse solids to a situation of reduced flow velocities would clearly aggravate the problem.

These problems, coupled with the possibly aperiodic collection of nongrindables and the by appointment bulky item collection, would necessitate both an intensive public information campaign as well as a unified operations center for refuse collection and sewer maintenance.

Frequency and Cost of Collection. Using relationships for the frequency and cost of collection of nongrindables as developed in the Phase I report,[29] it was estimated that between three and four regular collections would be needed in the Springfield case study area per year (in addition to increased frequency of the by appointment bulky waste collection), and that a typical annual per household collection cost would fall from $17.50 to $2.50.[30] Because of the present lack of detailed data, a more precise definition of the collection frequency is not yet possible.

Because of the drastically reduced collection frequency for nongrindables, and especially in view of the possible aperiodicity resulting from seasonal peaks, it may be necessary to send some form of media reminder to householders a few days in advance of the nongrindables collection. Clearly, it would be unreasonable for a householder to remember the days of collection if spaced at such long intervals. Such notice might entail considerable administrative effort, and would probably presuppose a centralized and computerized system run in conjunction with the operational control of the collection vehicles.

Disposal

Disposal methods would also be affected significantly. Because most of the nongrindable materials are incombustible, incineration of nongrindables is not a feasible proposition. On the other hand, recovery of metals from the ungrindables will doubtless be aided in the absence of all light, putrescible matter. But landfill disposal is the most likely option, until such time as resource recovery and recycling of metals becomes more widespread. Unfortunately, the economies of scale in conventional disposal methods will have a negative impact on the disposal of nongrindables under a wet systems implementation; a 90 percent reduction in volume will bring less than a 90 percent cost reduction, and the per ton cost of disposal will increase.

It has been argued that the cost of existing solid waste collection could be substantially reduced if the volume of domestic refuse were reduced by the elimination of relatively bulky glass containers resulting from a ban on "no-deposit no-return" bottles. But this would also benefit the wet system, as ground glass is one of the major refuse categories that can be expected to cause problems in sewer transport (see below, Section V).

SECTION VI

HYDRAULIC TRANSPORT*

Introduction

The key to the feasibility of the wet systems concept is the ability of an existing sewer system to transport ground refuse without adverse effects. Unfortunately, the literature and experience dealing specifically with the ability of sewers to transport solid waste is extremely limited, and only three studies were considered of any consequence to our analysis. One mentioned earlier was a result of depositing very coarsely ground refuse in large sanitary sewers performed in 1963 by the County Sanitation Districts of Los Angeles County.[2] The other two were studies conducted by Foster-Miller Associates for the Environmental Protection Agency.[31,32]

A detailed review of this literature shows that two conditions must be present for hydraulic transport in an existing system to be judged feasible;[33] a scour velocity of about 2.5 ft/sec is necessary to prevent accumulation in the sewer of the heavier components such as glass and metals, and the concentration of refuse must be below the so-called "limiting concentration" for the sewage-ground refuse mixture to have hydraulic properties similar to sewage alone. This limiting concentration is also a function of flow velocity, increasing with increasing velocity and depth of flow, and lies between about 0.5 and 1.5 percent refuse solids by weight.

Although the Foster-Miller experiments covered steady-state conditions in both straight sewer pipes and in a variety of appurtenances (including manholes and siphons), their conclusions of feasibility must be put in the light of actual rather than designed conditions in a sewer system. Some preliminary analysis showed that although both conditions are generally met in interceptors, there might be substantial difficulty in meeting them in lateral street sewers. Consequently, the focus of the case study investigation with respect to hydraulic transport was to establish the magnitude of maximum velocities in typical street sewers, and to establish the relationship between the quantity of freshwater needed for grinding and the limiting refuse concentration in the sewer. Obviously, by adding sufficient freshwater to the grinding, the limiting refuse concentration can always be met; the problem, however, is that such freshwater additions may be undesirable both from the viewpoint of increasing total freshwater consumption as from the viewpoint of increasing flows at the treatment plant.

Scour Velocity Investigations

The laboratory studies conducted by Foster-Miller Associates have determined that for the particle size distribution emanating from their preliminary grinder design, a minimum velocity of 2.5 ft/sec (0.76 m/sec) is needed to maintain self-cleansing conditions in sewers. Since steel cans have already been eliminated due to excessive power requirements for grinding, high grinding costs and problems in appurtenances, especially siphons, this velocity is required to transport the glass, ceramic, and aluminum components only. No determination was made as to how often or how long this scouring velocity should be present. However, in order to avoid excessive accumulation of debris, it would not be unreasonable to require daily scouring of settled materials. Otherwise, deposited materials may combine with grease or other cohesive materials to form a cake resulting in a further loss in hydraulic properties.

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*For more detailed discussions, see Meier, Kuhner and Martel, (Ref. 20), Chapter III and Meier, Kuhner and Bolton, (Ref. 22), Chapter IV.

Assuming unobstructed flow conditions, there are two occasions where sewers are incapable of providing the required 2.5 ft/sec (0.76 m/sec) scour velocity. The first occasion is where sewers are designed according to the minimum requirements of most health departments which specify a "minimum full-conduit velocity of 2 fps."[34] Since maximum flow velocities are achieved at full or near full flows, these sewers cannot be expected to flow faster than 2.0 ft/sec (0.61 m/sec). The second occasion is where sewers are not flowing full enough to attain a 2.5 ft/sec (0.76 m/sec) velocity.

Investigation of the Springfield sewerage system revealed that sewers laid at minimum slope (to produce a full pipe velocity of only 2.0 ft/sec) are not uncommon. It also revealed, through a sewer survey, that even in sewers where the design slope is great enough to produce velocities in excess of 2.5 ft/sec (0.76 m/sec), the quantity or depth of flow is insufficient. The highest maximum velocity reached during a 7 day survey of 7 lateral sewers in August 1973 was 1.62 ft/sec (0.5 m/sec), and the lowest maximum velocity occuring in a 24 hour period was 0.74 ft/sec (0.225 m/sec). The conclusion that glass and other high specific gravity material would accumulate in such sewers is inescapable.

One obvious alternative to resolve this problem would be the elimination of glass, ceramic and aluminum material from the list of grindables, along with steel cans, heavy gauge plastic and heavy gauge aluminum. However, this would increase the collection cost of nongrindables and would seriously reduce the convenience to the user. On the other hand, instead of prohibiting the grinding of glass and other high specific gravity materials , it may be feasible to simply flush accumulated materials from the affected sewer lines at regular intervals. The frequency of flushing would depend on the rate of accumulation and the effect of the accumulated deposits on the hydraulic properties of the pipe. Without actual experience or field test results, one can only assume a likely frequency. But based on some calculations which indicate an accumulation of about 2.2 inches of glass in a typical 8-inch lateral sewer per year, an intensive flushing program would probably be required. Discussions with municipal officials with great experience in sewer maintenance indicated the impossibility of accurate prediction in this area in the absence of actual data.

Another alternative to eliminating glass as a grindable item is to redesign the sewer system to achieve the minimum scour velocity of 2.5 ft/sec

(0.76 m/sec) at the shallower depths common in sewer flows. This would mean steeper sloped sewers and a more frequent use of lift stations. This might be considered feasible for newly developing and urban renewal areas that could readily implement new design standards. However, some sample designs and cost analyses quickly showed that a tripling of construction and operating cost was involved and this alternative, too, was rejected as a feasible proposition.

Grinding Water Investigations

The sewer survey showed that street sewers rarely, if ever, flow greater than half full. This is important because the limiting refuse concentration is strongly influenced by the flow depth. Foster-Miller defined limiting refuse concentration as that concentration at which the friction resistance is the same as that for water and beyond which the friction resistance increases rapidly.[35] Consequently, if refuse mixtures above the limiting concentration are introduced into the sewerage system, reduced flow characteristics would result. Figure 3 shows the relationship between limiting refuse concentration and flow depth. For the depths of flow normally experienced in street sewers (between .1 and .3 d/D or d = 2 inches) it appears that the limiting concentration should be in the vicinity of 0.5 percent, instead of 1.0 percent as originally thought (the latter figure being used by Foster-Miller as a basis for the grinder design). However, in the larger interceptors where greater depths of flow can be expected, the limiting refuse concentration may be as high as 1.5 percent if flowing full or near full.

Since the ground refuse must flow through the street sewers of residential areas before discharging into an interceptor, the lower limiting refuse concentration of 0.5 percent should govern the dilution water requirements at each grinder installation. This is unfortunate because the lower limiting refuse concentration (0.5 percent) is made to apply in an area where the least amount of dilution water is available. In street sewers, only residential flows and some infiltration can be expected whereas in the larger interceptors, dilution water is available from industrial and commercial sources as well.

The relationship between the amount of grinding water required and the percent solids content for various refuse generation rates is shown in Figure 4. This graph was developed from the equation:

$$q = \frac{L(1-\Omega-\lambda)}{8.34\lambda}$$

where q is the gallons of grinding water required per capita per day, L is the pounds of refuse per capita per day, Ω is the moisture content of the refuse (assumed to be 20 percent) and λ is the grinding consistency ($0<\lambda<1$). Note that in order to satisfy the limiting refuse concentration of 0.5 percent, a grinding water requirement of between 20 and 90 gals/cap/day (76 and 341 ℓ/cap/day) is needed, depending on the refuse generation rate. For the average refuse generation rate of Springfield, which

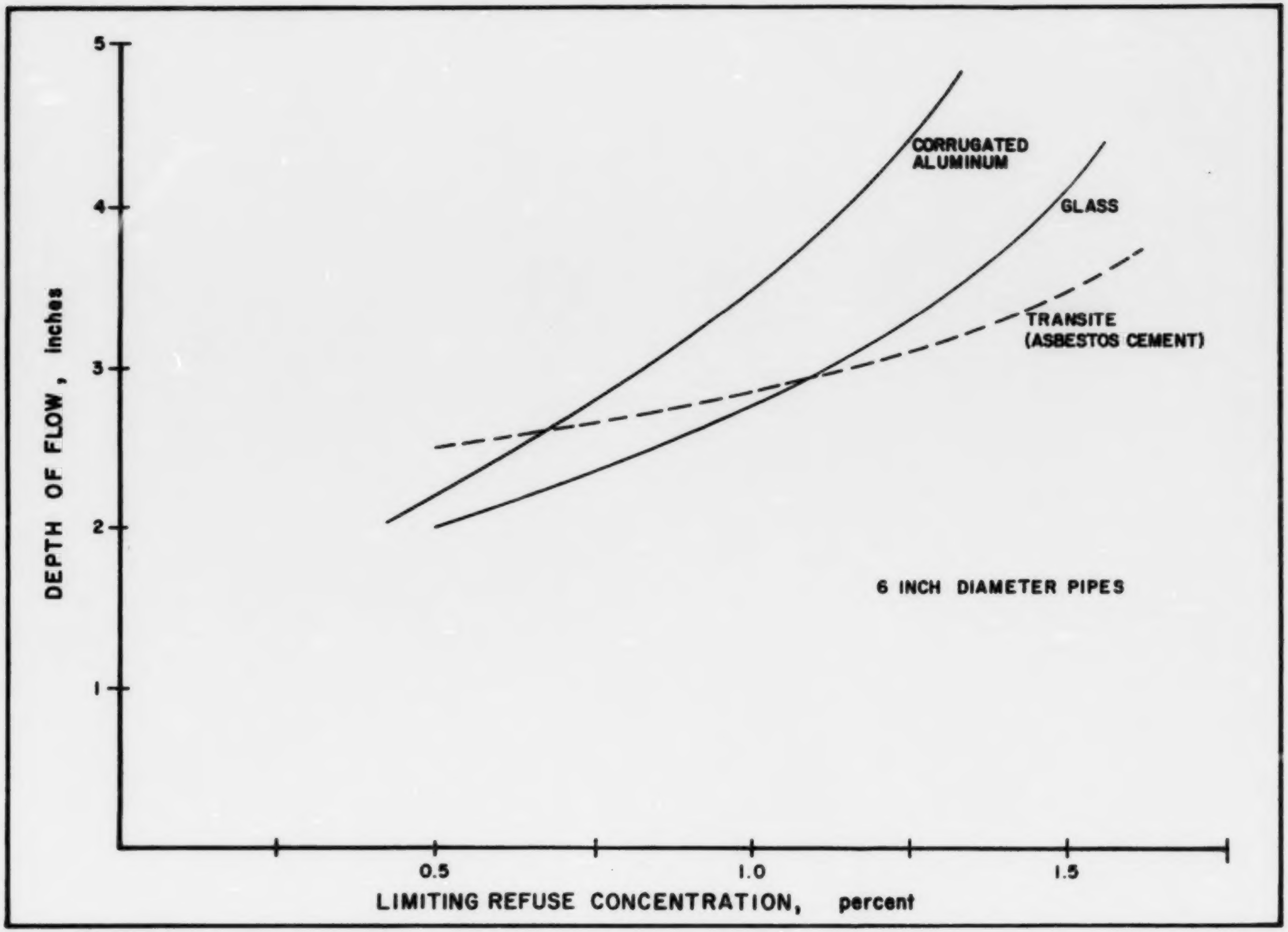

Figure 3: Limiting Refuse Concentrations for Hydraulic Transport in Sewers
(Source: Guzdar & Rhee, op. cit., p. 98)

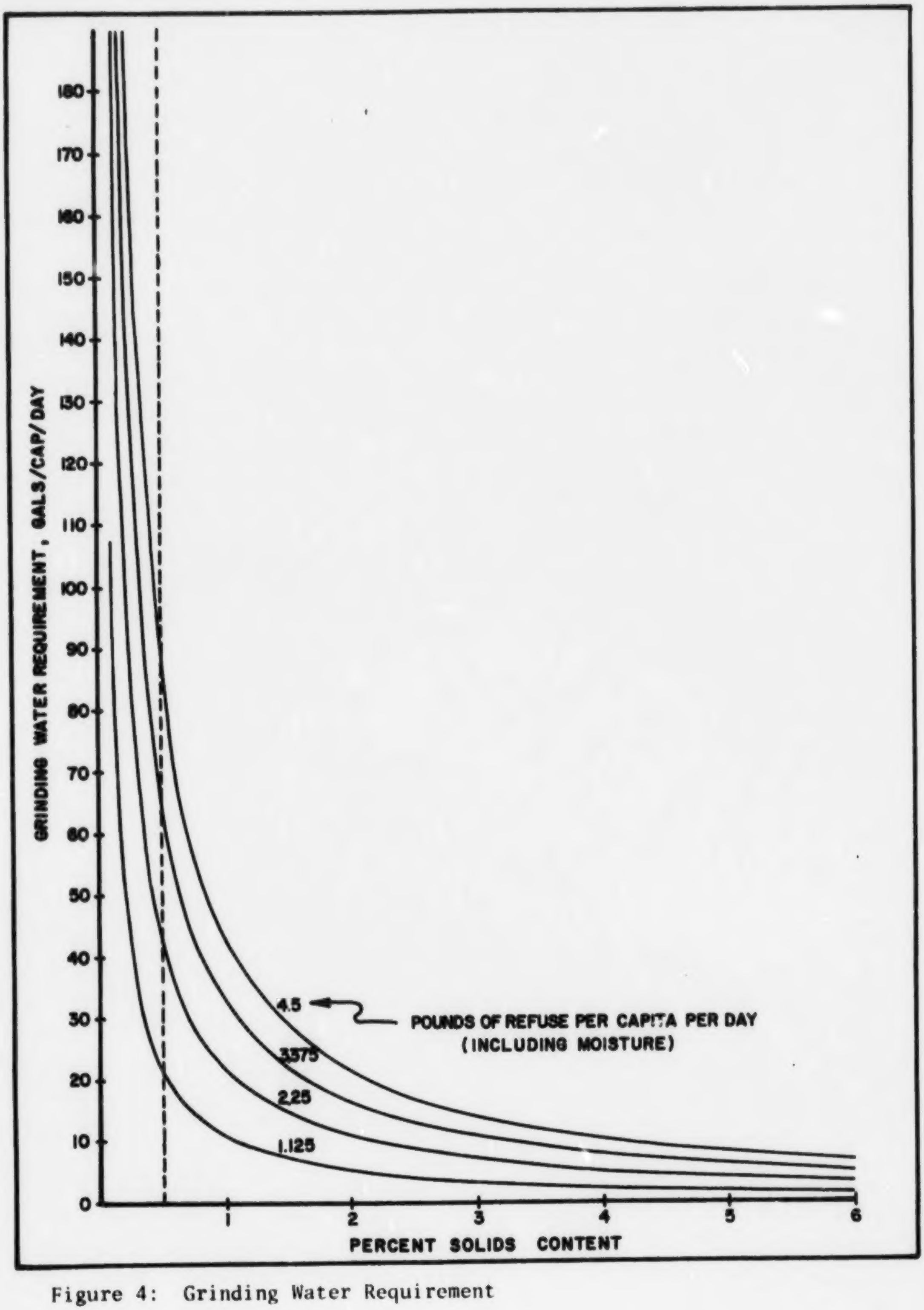

Figure 4: Grinding Water Requirement

is 2.56 lbs/cap/day (1.14 Kg/cap/day), the amount of grinding water required is approximately 48 gals/cap/day (182 ℓ/cap/day).

Because of this high grinding water requirement, Foster-Miller suggested that household nonfecal wastewater be stored and reused for grinding. For the purpose of this analysis, nonfecal wastewater includes discharges from all plumbing fixtures except the toilet. Therefore, the total household water consumption required to allow refuse grinding using only nonfecal wastewater is the sum of the household grinding water requirement and the household fecal wastewater component. The household grinding water requirement can be determined by multiplying the number of persons per household times the per capita grinding water requirement determined from Figure 4. The household fecal wastewater component can be calculated based on an average toilet use of 4 uses/cap/day at 5 gals/use (19 ℓ/use). For an average household with 3 persons per household, the household water consumption rate needed to grind refuse is approximately 204 gals/HH/day (3 persons per household x (48 + 20) gals/cap/day), which is substantially above actual consumption rates.

The water consumption records were examined for homes in two neighborhoods in Springfield, one of 36 single-family homes, the other of 50 duplexes. Analysis showed that the single family home area would require an 8.5 percent increase in water consumption in the winter and a 39 percent increase in the fall. The duplex area would require a 3.7 percent increase in the winter and a 12 percent increase in the fall. The seasonal dependance is dictated by the seasonal fluctuations in refuse generation, as noted in Section IV, above. Considering that over 65 percent of the housing units in the city of Springfield are either single-family homes or duplexes, this would represent a large increase in total water demand. Moreover, while increased flows could probably be accommodated in the lateral sewers without difficulty (because, as shown by our survey, they rarely flow at more than half depths), there may be problems in interceptors that are more likely to reach flows nearer their design value, and of course, the total inflow at the sewage treatment plant would also increase. A conclusion from this analysis is that much of the garden wastes collected in the fall, which is largely responsible for the higher refuse quantities in that season, cannot be ground for reasons of unacceptable freshwater demands, and would therefore need a special conventional collection.

Hydraulic Transport at Higher Than Critical Concentrations

The large quantity of dilution water required to maintain hydraulic flow characteristics similar to water raises the question as to the impact of depositing refuse in sewers at concentrations higher than the limiting refuse concentration (0.5 percent). If higher refuse concentrations of 1 percent and more were hydraulicly transportable, substantially less dilution water would be required. From Figure 4 it can be seen that at 1 and 2 percent refuse concentrations, dilution water requirements can be reduced substantially. This in turn would mean that a much larger percentage of homes would possess the necessary dilution water and very little additional fresh water would be needed. Also, the laboratory experiments of Foster-Miller have shown that flows at higher refuse concentrations (2 percent and above) have the ability to maintain heavier particles in suspension. This would eliminate the need to attain a specific scour velocity to remove settled materials. However, these heavier particles would likely settle out as the mixture is diluted further downstream.

But, Foster-Miller also noted that head losses increase dramatically at refuse concentrations above the limiting refuse concentration. Consequently, mixture velocities would be less than for sewage alone, or for refuse mixtures below the limiting refuse concentration. Depending on the condition of the sewer, this could cause more frequent blockages. Also, the detention of sewer flows may encourage septic conditions which would be more objectionable in residential areas. Although sewers can be expected to flow fuller as a result of the decrease in velocity, this is not expected to be a problem since most street sewers are overdesigned with respect to hydraulic capacity as evidenced in the sewer survey, and rarely flow above half-full.

Thus although there appear to be some benefits to be derived from grinding and transporting refuse mixtures at higher than critical concentrations, it is difficult to make judgments of its technical feasibility until further experiments have been conducted.

Alternatives to Hydraulic Transport in Gravity Sewers

A number of alternative modes of hydraulic transport were examined in the early stages of the study, but rejected from further consideration either for reasons of lack of data or for obvious technical reasons at the scale of application here under investigation. Briquette and slug flow systems, investigated by the Stanford Research Institute for point-to-point pipeline transport of refuse[15] were rejected for both technical reasons and because of the obvious impossibility of providing briquette and slug forming equipment at a scale smaller than neighborhood.[36] Similarly, pressure systems were rejected on the basis of both cost (since a new pressure conduit would need to be built in existing areas) and operational difficulties.[37]

SECTION VII

TREATMENT*

Introduction

There is a critical lack of information on the physical-chemical characterization and treatability of ground refuse in sewage, and therefore accurate predictions of the impact of ground refuse to an existing treatment facility, or detailed design specifications for new facilities, are not easy. Indeed, the only comprehensive study is that undertaken by Metcalf & Eddy[38] as part of the initial Foster-Miller contract, although some limited information is also available from the experiments conducted in the early sixties in Los Angeles.[2]

A detailed review of this literature and other sources considered relevant is contained in Chapter IV of the Preliminary Assessment,[20] and we shall here summarize only the most important conclusions:

- Existing grit chambers would probably be adequate to handle increased load; major problem would be increased entrapment of organics and paper fibers.

- Suspended solids (SS) concentrations into primary settling units would increase about 10-fold over existing levels. Existing primary settlers would probably be adequate, but need much strengthened skimming and sludge scraping devices. BOD and SS concentrations in the effluent would be of the same order of magnitude as those encountered at existing treatment plants.

- Screens were found by Metcalf & Eddy to be effective as a primary treatment device, especially the Bauer "hydrosieve."

- The need for equalization of either load or flow is largely unknown, because the hour-to-hour patterns of refuse grinder operation are still conjectural.

- Secondary treatment appears to be little affected by the addition of ground refuse. Long-term BOD exhertion studies showed no inhibitory effects and identical rate constants. Phosphorous and nitrogen were determined to be adequate, with little change over the case of sewage alone. Heavy metal concentrations were also largely unchanged, with no evidence of toxicity.

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*See Meier, Kuhner and Bolton, (Ref. 22), Chapter V and Meier, Kuhner and Martel, (Ref. 20),Chapter IV for detailed discussions. The problems of sludge handling and disposal are discussed also in Section VIII of this report, below.

- Theoretical analyses of the maximum mercury concentration that might be introduced by residential refuse showed the possibility of mercury concentrations in sewage substantially higher than those encountered today. Metcalf & Eddy's measurements, however, showed no increase.

- The impact of ground refuse addition on advanced waste treatment was concluded to be marginal. Tertiary polishing devices (e.g., microstrainers) were the only type of AWT that might need to be specified for reasons of ground refuse additions because of the difficulty in aerobic degradation of cellulose fibers. The impact on phosphorus, nitrogen or dissolved organics removal processes was considered immeasurable in the absence of data.

Because of the difficulties encountered in making generalizations, considerable effort went into an examination of treatment in the case study area, using mathematical simulation techniques as the major tool. The mathematical model utilized for this purpose is described in detail in a separate report.[23] The most immediate shortcoming of using a mathematical model based primarily on design relationships valid for conventional sewage is that the addition of ground refuse may dramatically change the physical-chemical relationships involved. Whenever possible, such changes were incorporated, but the basis for the changes were the very limited studies discussed above and hence may well be subject to question. Nevertheless, in the judgment of the writers and the review panel, the results generated by the model were consistent with the goals of the study, and, whatever their shortcomings, certainly an improvement over mere qualitative and subjective opinions as to the consequences of ground refuse additions.

Existing Treatment Facilities in the Case Study Area

At the present time, Springfield utilizes two wastewater treatment facilities, each providing primary treatment for domestic sewage and most of the industrial wastes in the city. The smaller facility, Indian Orchard Treatment Plant, is located in the northeast section of the city on the Chicopee River. At present the plant handles only domestic sewage from the Indian Orchard section of Springfield, and wastes from the Monsanto industrial complex are dumped directly into the river. The nominal capacity of the plant is estimated at 3.0 mgd (11,355 m^3/day). The treatment process consists of screening, grit removal, and sedimentation prior to discharge of the unchlorinated final effluent. Settled sludge is digested, dried on glass-covered drying beds, and used as fill.

The major portion of Springfield's waste load is treated at the main treatment plant located on the Connecticut River at Bondi Island in Agawam. In addition to Springfield, the plant presently treats wastes from West Springfield, Agawam, and parts of East Longmeadow. The treatment facility is quite old, having been completed in 1940 as a Works Progress Administration (WPA) project. It provides units for coarse screening, grit removal, comminution of solids, and primary settling. Sludge handling facilities include heated digestion tanks, elutriation tanks, a vacuum filter, and land disposal site. There is no chlorination before discharge. Figure 5 provides a schematic of the present operation.

Although the design capacity of this existing plant is rated at 30 mgd, flows in excess of this figure are regularly recorded, with a resulting decrease in removal efficiency. Flows beyond 45 mgd (170,325 m^3/day) are automatically bypassed directly to the Connecticut River.

The primary factor limiting the treatment capacity of the existing plant is the sludge disposal system. The digestion process is impeded when large volumes of sludge are fed to the digestors. Also, one unit must be dewatered each year for grit removal. As a result of the digesters' inability to handle the present sludge volumes, approximately half of the settled sludge is now bypassed directly to the elutriation tanks. There the two sludge streams, digested and raw, are mixed prior to vacuum filtration.

The computer model representation of the existing system further stressed the inadequacy of the present removals.[39] On the basis of the model, it was estimated that only 48 percent of the BOD is removed by the existing facility. The theoretical addition of 2.56 pounds of refuse per capita per day (1.15 Kg/cap/day) would obviously aggravate the present plant limitations even further.

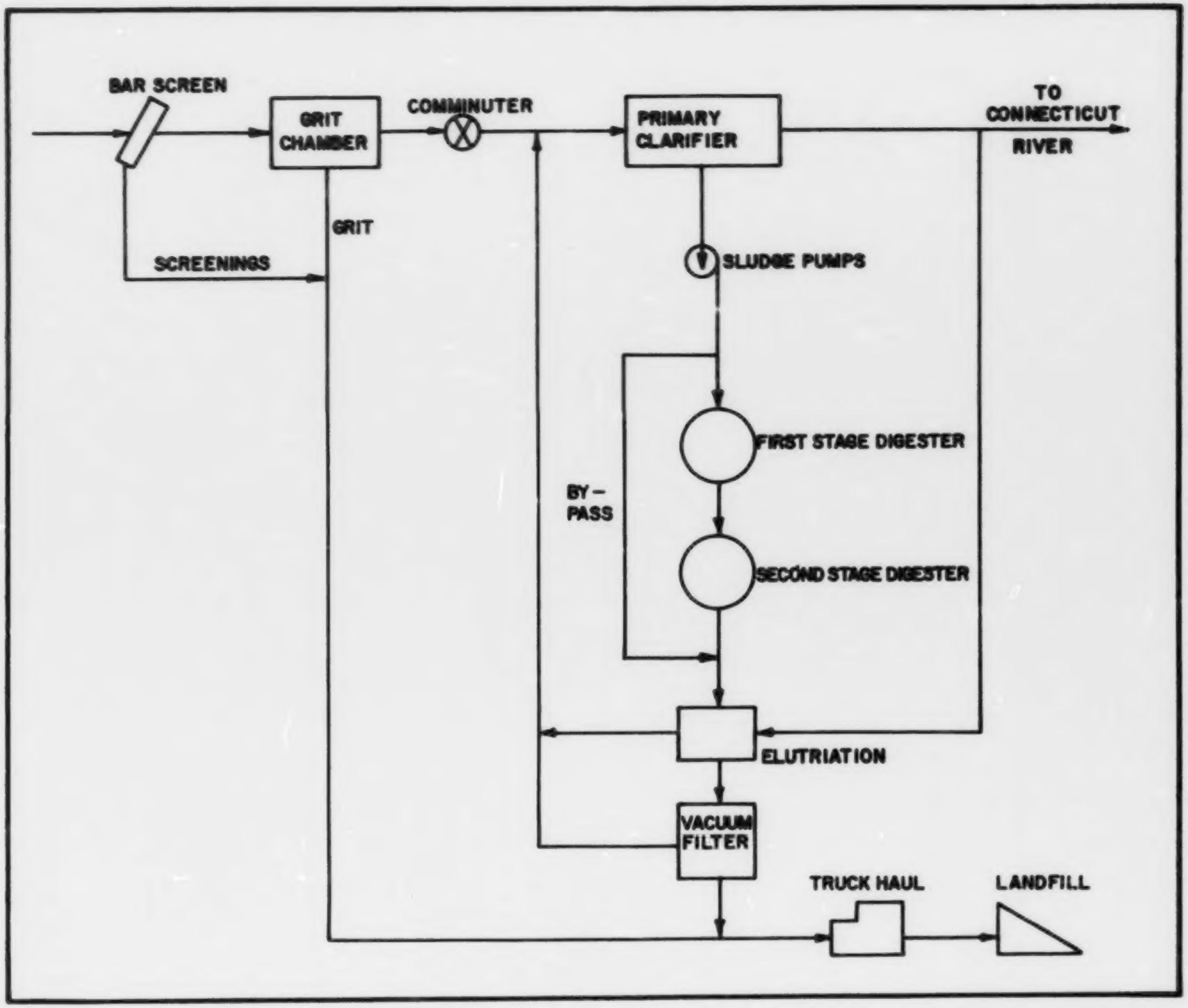

BAR SCREEN
GRIT CHAMBER
COMMINUTER
PRIMARY CLARIFIER
TO CONNECTICUT RIVER
GRIT
SCREENINGS
SLUDGE PUMPS
FIRST STAGE DIGESTER
BY-PASS
SECOND STAGE DIGESTER
ELUTRIATION
VACUUM FILTER
TRUCK HAUL
LANDFILL

Figure 5: Existing Process Configuration at the Springfield Wastewater Treatment Plant

Proposed Sewage Treatment Plant

In light of the inadequacy of the present plant, the city of Springfield has contracted for development of a new treatment facility. The plan calls for abandonment of the Indian Orchard facility, and construction of a new plant at the Bondi Island site. This new plant would provide secondary treatment for all the present participant towns and, in addition, would include the town of Ludlow and the industrial flow from the Monsanto Chemical Company. The rates of flow and strengths of wastewater projected for each contributor for the design year (1990) are listed in Table 3. The plant as designed will consist of bar screens, grit separation units (cyclones), primary settling tanks, aeration tanks, flocculation tanks, final settling and chlorination facilities. Pumping units will be provided to discharge the plant effluent into the Connecticut River during flood seasons. The sludge handling facilities will include gravity thickeners for primary sludge, flotation thickeners for waste activated sludge, holding tanks for both primary and waste activated sludge, and wet oxidation facilities to sterilize and reduce sludge volumes and thus the size of the vacuum filters. A process schematic of the proposed 64.1 mgd (264,618 m^3/day) waste treatment plant is shown in Figure 6.

Table 3: Estimated Rates of Flow and Strengths of Wastewater From All Contributors

City	Flow, mgd[a] Average	Peak	BOD lbs/day[b]	S.S. lbs/day[b]
Ludlow	2.7	8.2	4,500	3,380
Monsanto	8.8	19.1	48,500	23,500
Indian Orchard	3.5	15.7	7,300	5,850
East Longmeadow	2.3	7.4	3,400	4,400
Springfield	31.7	91.7	45,700	44,500
West Springfield	9.0	16.9	11,300	16,200
Agawam	6.1	15.4	11,800	14,500
TOTAL	64.1	174.1	132,500	112,330

[a] mgd x 3,785 = m^3/day

[b] lbs/day x .454 = Kg/day

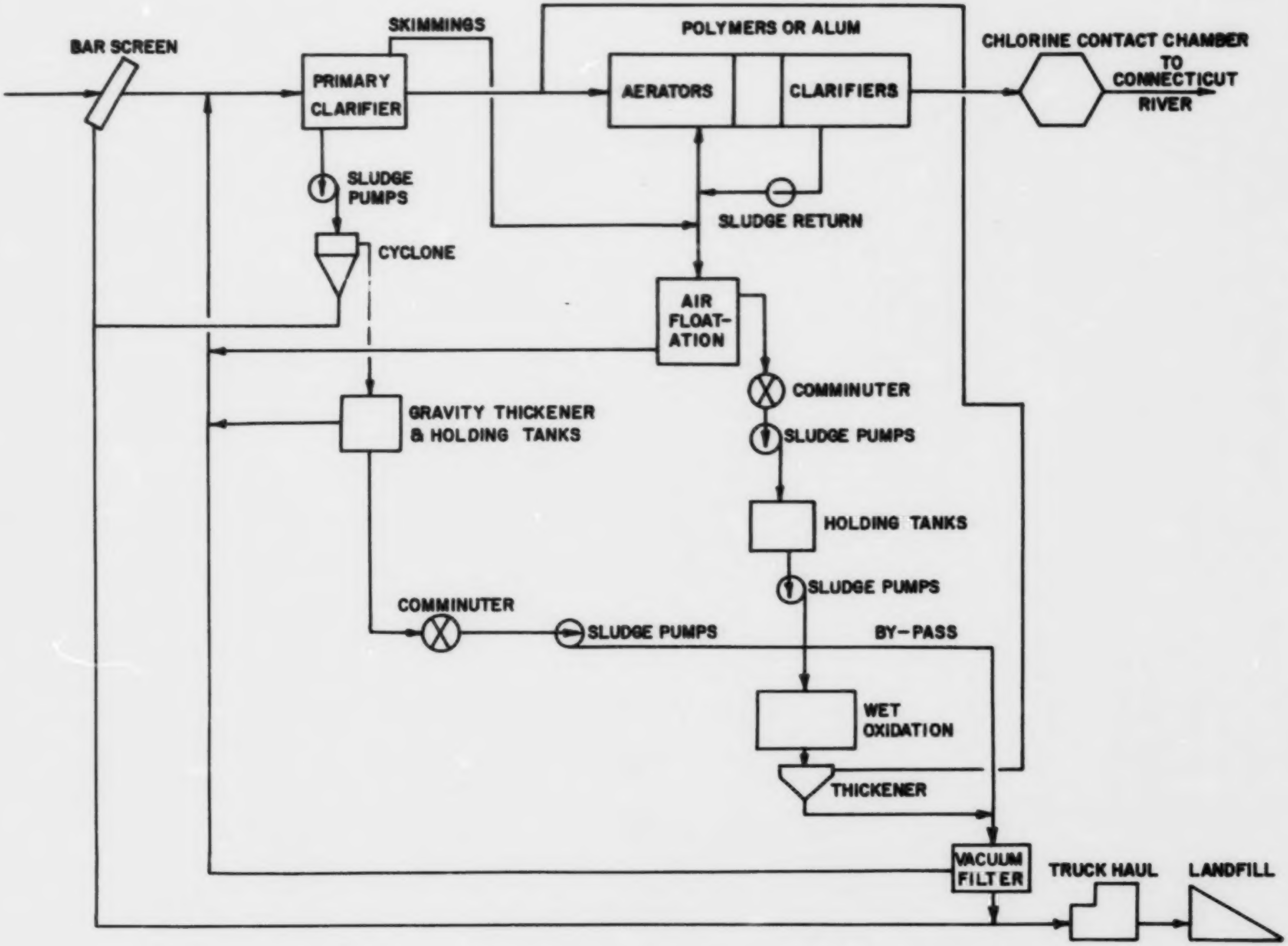

BAR SCREEN
SKIMMINGS
PRIMARY CLARIFIER
POLYMERS OR ALUM
AERATORS
CLARIFIERS
CHLORINE CONTACT CHAMBER
TO CONNECTICUT RIVER
SLUDGE PUMPS
SLUDGE RETURN
CYCLONE
AIR FLOAT-ATION
COMMINUTER
SLUDGE PUMPS
GRAVITY THICKENER & HOLDING TANKS
HOLDING TANKS
SLUDGE PUMPS
COMMINUTER
SLUDGE PUMPS
BY-PASS
WET OXIDATION
THICKENER
VACUUM FILTER
TRUCK HAUL
LANDFILL

Figure 6: Planned Process Configuration at the Springfield Treatment Plant.

Generation of Input Parameters

In order to estimate what effect the inclusion of ground refuse would have on the proposed plant's performance, it is necessary first to model the plant as it is presently envisioned[42] and then to adjust the input quality parameters to reflect the additional load occasioned by 1.79 pounds of ground refuse per capita per day (0.81 Kg/cap/day).

As noted previously, there is a critical lack of information on the character of ground refuse in sewage. For this reason, figures dealing with the physical and chemical characteristics of ground refuse in sewage must necessarily be best estimates based on the limited information which does presently exist. Because of the large amounts of solids and floatables present in sewage containing ground refuse, and the subsequent problems these solids cause in laboratory analyses, all past tests have been performed on primary effluents. In the Metcalf and Eddy study,[43] ground refuse was added to Boston sewage in varying concentrations ranging from 0.25 percent to 1.0 percent based on a per capita daily wastewater generation of 100 gpcd (378.5 ℓ/cap/day). In Springfield, records show that about 140 gallons (530 litres) of sewage are generated per person per day. Thus, at a refuse generation rate of 1.79 lb/cap/day (0.81 Kg/cap/day) the loading on the treatment plant will average only about .2 percent by weight.

In order to estimate the quality parameters associated with a refuse-sewage stream of this strength, it is necessary to estimate the nature of the primary effluent and then to work back, using a solids balance to obtain reasonable values for the influent flow. Following this procedure, estimated concentrations associated with a 1.79 lb/cap/day (0.81 Kg/cap/day) loading in the Springfield sewerage system were developed. These concentrations, along with those of the sewage flow, are listed in Table 4. The 1.79 lb/cap/day is based on the assumption that of the total 2.56 lb/cap/day generation rate, 10 percent by weight is nongrindable and 20 percent by weight is moisture. In the following analysis, therefore, the lb/cap/day figures used are on a dry weight basis.

Effects of Refuse on the Proposed Bondi Island Plant

The imposition of ground domestic refuse on the proposed Bondi Island Treatment Plant would affect some processes to a greater degree than others. It was our intent, through the computer model, to highlight those plant functions which would be most severely limited. Once these problem areas have been designated, it is then possible, again with the help of computer simulations, to try various alternative schemes in order to obtain the best quality effluent at the least possible cost.

As might be expected, the increased concentrations of solids and BOD will greatly influence the sizing of many plant components, especially sludge handling processes. It is estimated that a loading of 1.79 pounds of

Table 4: Present and Projected Waste Concentrations

Parameter	mg/ℓ Present Sewage	mg/ℓ With .2% Refuse
Solid Organic Carbon	105.0	181.0
Solid Nonbiodegradable Carbon	30.0	60.0
Solid Organic Nitrogen	10.0	12.0
Solid Organic Phosphorus	2.0	4.0
Solid Fixed Matter	73.0	473.0
Solid BOD (SBOD)	93.0	113.0
Volatile Suspended Solids	91.0	1,041.0
Total Suspended Solids (TSS)	164.0	1,514.0
Gross Suspended Solids (GSS)	0.0	525.0
Normal Suspended Solids (NSS)	154.0	699.0
Heat, BTU/gallon	616.0	5,692.14
Grit (GRIT)	10.0	290.0
Dissolved Organic Carbon	43.0	73.0
Dissolved Nonbiodegradable Carbon	19.0	20.0
Dissolved Nitrogen	11.0	20.0
Dissolved Phosphorus	5.5	8.25
Dissolved Fixed Matter	259.0	500.0
Alkalinity, mg/ℓ as $CaCO_3$	92.0	250.0
Dissolved BOD	40.0	115.0
Dissolved Organic Matter	160.0	320.0

ground refuse per capita per day (0.81 Kg/cap/day) will result in an average total solids concentration of 1,514 mg/ℓ entering the plant. This figure is roughly ten times the present loading. A great portion of these added solids will be in the form of grit from ground glass (290.0 mg/ℓ), and gross solids from packaging and the like (525.0 mg/ℓ). The quantities of these two constituents place particular constraints on the design and operation of the grit handling facility. The proposed plant will feed all the primary sludge, including the grit, to a cyclone separator. Although this scheme should provide adequate removal for all projected grit quantities resulting from sewage alone, the greatly increased concentrations expected as the result of ground refuse addition could cause numerous problems with clogging and inefficient grit separation. Rather than increase the capacity of the cyclone separators, a cheaper and more efficient solution was found to incorporate a conventional aerated grit chamber and grit washer prior to primary settling. Such a modification will have the effect of removing grit prior to primary sludge pumping, and should provide a more effective operation under the changed conditions anticipated with ground refuse additions.

As presently envisioned, the proposed plant will utilize two separate sludge thickeners. Primary sludge will flow from the cyclone separator directly to a series of gravity thickeners. Waste activated sludge, on the other hand, will be thickened to about 4 percent solids by use of six air flotation units. There are holding tanks for each stream of thickened sludge prior to mixing and injection into the wet air oxidation unit. The ratio by weight of dry solids of primary to waste activated sludge in a conventional wastewater treatment plant handling the sewage alone is about 1.2:1, or even 0.5:1.[44] By comparison, the ratio which could be expected by adding 1.79 lb/cap/day (0.81 Kg/cap/day) ground refuse soars to about 12:1, primary sludge to secondary. At such high ratios, the cost-effectiveness of two separate thickening processes would appear questionable. Because the waste activated sludge portion is so small, it can be mixed with the primary sludge and then thickened together with little loss of efficiency, but at great cost savings.[45] Therefore, should a wet system of refuse disposal be initiated, it would be more economic to thicken both sludge streams together in a gravity thickener. This is confirmed by the cost analyses presented below.

The wet-air oxidation process operates under the principle that organic substances may be oxidized under high pressures at elevated temperatures with the sludge in a liquid state by feeding compressed air into the pressure vessel. The process was developed in Norway for pulp-mill wastes, but has been revised for the oxidation of raw sewage sludge, pumped directly from the primary settling tank or thickener. Combustion is not complete. For the Springfield plant, a low pressure oxidation unit has been specified. Performance characteristics of such a unit include a 15 percent reduction of Chemical Oxygen Demand (COD) and a 30 percent destruction of the insoluble volatile matter. The end product of the process is a sterile dewaterable and oxidized liquid mass. As a result of the rather low degree of oxidation and the destruction of the volatile solids, a good portion of the solid COD is converted to dissolved COD and returned with the supernatant from the vacuum filter to the head of the plant. For normal sewage this additional COD loading is not significant, but when ground refuse has been added to the sludge stream, the COD of the supernatant can be expected to be of such large magnitude as to severely affect the aeration processes to which the vacuum filter supernatant is returned.

This would not be as serious a problem if anaerobic digesters were used since the digesters convert organic acids to methane gas and carbon dioxide, and thus remove a great deal of the COD from the return stream. As noted by Kos *et al.*,[46] there is sufficient evidence to show that ground refuse can be satisfactorily digested with sewage sludge. Moreover, contingent on a favorable local market, this technique can provide a valuable commodity through methane gas production. For these reasons, we would recommend that should ground refuse be added to the sewage stream at Bondi Island, anaerobic digesters would provide a better solution than wet-air oxidation. However, if the methane gas would yield less than $0.80/1000 cu ft, our detailed studies on sludge handling show that the digester should be omitted, with the thickener underflow fed directly to holding tanks and vacuum filters.[47]

In addition to those processes already mentioned, many other plant functions would need to be enlarged to handle the additional load; foremost among these are the sludge holding tanks, sludge pumps, thickeners and the aeration basins.

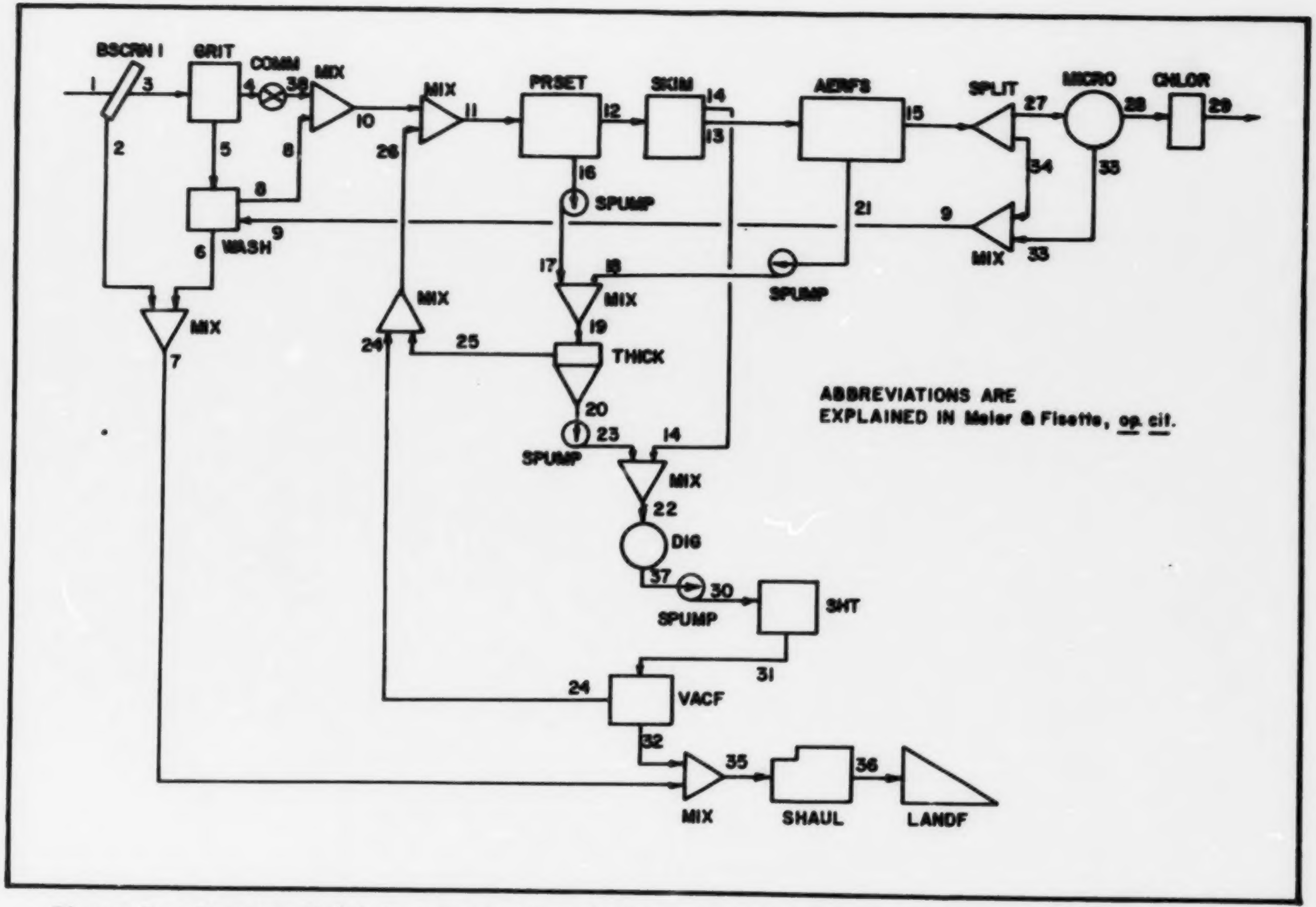
The computer analyses indicate that as a result of ground refuse additions dissolved BOD loadings into the aerator will increase threefold and solid BOD would increase by a factor of 1.2. Total solids to the aerator would increase by a factor of about 4.5. In order to achieve the same degree of BOD removal as the proposed plant with just sewage, the aeration basin would need to be substantially enlarged. This seems in sharp contrast to the primary settler, which would not need to be enlarged. The reasons for this apparent discrepancy is that using existing settling curves, the great majority of solids added by the ground refuse would either float to the surface or settle easily within the alotted detention period. This fact is further detailed by comparing solids concentrations in primary and secondary sludge stream. With ground refuse added, the total solids in the primary sludge stream increases elevenfold over that expected from just sewage. On the other hand, the solids in the waste activated sludge stream remain virtually the same for both cases.

This increase in primary sludge solids will affect the sizing of all subsequent sludge handling processes. Accordingly, there will be increased capacity and cost associated with the sludge pumps, sludge holding tanks, thickeners, digesters and vacuum filters. Specifics regarding these processes, including landfill requirements, are discussed in detail in the separate report on sludge handling and disposal.[48]

Figure 7 shows the computer model representation of the recommended plant; the notation and abbreviations are detailed in Meier and Fisette.[24] We have indicated that a microscreen would be used just prior to chlorination. The effect of the screen would be to compensate for seasonal variations and to polish the effluent by removing many of the trace solids (cellulose) which might remain. The result is that the plant as a whole will remove 92 percent of the BOD from the refuse-sewage mixture and will provide an effluent which is at least as good as that forecast for the proposed plant with sewage alone.

In addition to these quality parameters outlined in Table 4, there remain a number of variables associated with ground refuse in sewage about which we have little or no knowledge. These include possible effects connected with grease and oil, toxic materials and heavy metals. It is important that a complete investigation into the nature of ground domestic refuse in sewage be conducted in order that effects on the various treatment processes associated with these additional parameters might be fully addressed in the preliminary phase of our investigations.[49]

Seasonal Variations. As detailed in Section III of this report, one can expect substantial seasonal variations in both the character and quantities of refuse generated. Just as these variations affect present


BSCRN I
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ABBREVIATIONS ARE
EXPLAINED IN Meier & Fisette, op. cit.

Figure 7: Computer Model Representation of the Recommended Treatment Process Configuration for Ground Refuse

disposal techniques, they would also affect treatment plant operation should these peaks be ground into the sewers.

Table 5 shows the expected seasonal variations in influent quality parameters, given that the fractions of each refuse category ground remain constant throughout the year.[50] Clearly, the peak seasonal load would be expected in the fall.

Table 5: Seasonal Variations Due to Ground Refuse Addition

Parameter*	Summer	Fall	Winter	Spring	Annual Average
SBOD, ppm	112.25	118.92	108.32	112.95	113
VSS, ppm	1002.80	1354.00	794.97	1012.05	1041
TSS, ppm	1450.00	1850.00	1213.50	1542.30	1514
DBOD, ppm	112.12	133.00	100.26	114.58	115
GRIT, ppm	267.50	277.45	260.36	354.76	290
GSS, ppm	518.17	628.84	464.94	488.65	525
NSS, ppm	665.85	944.69	491.73	692.73	699

*See Table 4 for abbreviations.

In order to evaluate the effect such a seasonal peak would have on the treatment plant operation, the computer model was run first with input parameters representative of fall alone, and then with the average values for summer, winter and spring. The results of this analysis indicate that some additional capacity would be needed to handle the increased sludge volumes, but that the major impact would be on secondary treatment facilities. It is estimated that the fall seasonal loading would result in a 44 percent increase in total solids and 20 percent increase in BOD entering the aeration basin. These increased concentrations would therefore require either increased aerator capacity or subsequent microscreening to provide equivalent removal efficiency. Microscreening affords the cheaper of the two alternatives ($2,000,000 as against $3,000,000 to increase the size of the aerator) and thus is included in our recommended treatment scheme.

Cost Analysis

As mentioned previously, the intent of this analysis is to provide a treatment scheme which could handle the higher concentrations of pollutants occasioned by ground domestic refuse, and yet not jeopardize the C classification of the Connecticut River at Bondi Island. The costs associated with such a proposal are necessarily a prime consideration in determining the feasibility of the wet systems concept.

According to the construction specifications of Springfield's consultants,[51] the Bondi Island plant will require a capital investment of $36,865,000. Our computer analysis provides a somewhat lower figure of $34,460,912. One reason for this discrepancy is that the computer program relies on national construction cost averaged to predict individual plant costs, yet at the present time New England costs exceed the national average. Also, in the case of particular plant operations, the two cost figures may not describe identical processes. For example, the consultant's specification of sludge conditioning and filtration costs may include more than just wet air oxidation and vacuum filtration, which the computer uses to establish its cost figure. Moreover, it would be unreasonable to expect a program that is focussed on preliminary design to yield identical results with those of the final construction specifications. Table 6 provides a breakdown of the capital expenditure required for analysis. Using an interest rate of 6 percent and a 25 year amortization period, the capital cost would range between 11.50¢/1000 gallons (3¢/1000 ℓ) and 12.25¢/1000 gallons (3.25¢/1000 ℓ). Operation and maintenance costs are projected to be 5.8¢/1000 gallons (1.5¢/1000 ℓ), such that the total cost of treatment would be 17.3 to 18.05¢/1000 gallons (4.6 to 4.7¢/1000 ℓ) of sewage treated.

If the individual plant processes were to be kept as presently planned, but enlarged to handle ground refuse, the total treatment cost of these same facilities is estimated at 30.64¢/1000 gallons (8.04¢/1000 ℓ), or slightly less than twice the projected present cost for sewage alone. But, as mentioned previously, the introduction of ground domestic refuse would require modification of a number of plant processes, particularly those dealing with sludge handling, in order to avoid problems of clogging and inefficient operation. Therefore, it is more instructive to compare existing costs for sewage alone with those associated with the recommended wet systems treatment scheme.

The initial capital cost of this modified treatment facility (Figure 7) is estimated at $49.4 million. Operation and maintenance would run in the neighborhood of 7¢/1000 gallons (1.85¢/1000 ℓ), such that the total treatment cost would be only 23¢/1000 gallons (6¢/1000 ℓ) or just more than 1.3 times the projected cost for sewage alone. The major cost savings would result from the replacement of the wet air oxidation unit with a conventional anaerobic digestion system. There was no provision in the cost analysis for income derived from methane gas production. Additionally, the computer model of the recommended treatment stream was run to simulate equivalent removal efficiency for a .4 percent by weight mixture of ground refuse in sewage, corresponding to a doubling in refuse generation rate to 3.58 lbs/cap/day (1.62 Kg/cap/day). Despite this increase, economies of scale results in an estimated cost increase of only 30 percent, up to 29.9¢/1000 gallons (8.0¢/1000 ℓ). A summary of the cost data for treatment of ground refuse in sewage is provided in Table 7.

Table 6: Treatment Costs for Sewage Alone; Planned Bondi Island Treatment Plant

Item	Consultant's Estimated Project Cost	Computer Estimated Project Cost
Grit and screenings	$ 520,000	$ 127,270
Primary settling tanks	4,160,000	4,076,472
Secondary treatment facilities	12,630,000	11,177,441
Sludge pumping	650,000	352,833
Sludge conditioning and filtration	5,980,000	4,823,516
Sludge thickening	840,000	2,175,906
Chlorination	1,250,000	890,763
Electrical and Instrumentation	3,250,000	3,250,000*
Yard piping	2,600,000	2,600,000*
Site preparation	4,290,000	4,290,000*
Land acquisition and fees	695,000	696,711
TOTAL CAPITAL COST	$36,865,000	$34,460,912
	¢/1000 gallons	
TOTAL AMORTIZATION COST	12.25	11.50
TOTAL O & M COST	5.8	5.8
TOTAL TREATMENT COST	18.05	17.3

*Reproduced consultant's figures.

Table 7: Treatment Costs for Sewage Containing Ground Domestic Refuse

Item	Proposed Plant .2% Refuse	Recommended Plant .2% Refuse	Recommended Plant .4% Refuse
Grit & screenings	$ 128,225	$ 72,951	$ 84,026
Primary settling tanks	4,140,375	3,972,556	3,953,085
Secondary treatment facilities	16,906.792	15,764,124	20,940,392
Sludge pumping	551,872	885,936	1,159,230
Sludge conditioning & filtration	13,542,624	7,876,073	13,951,909
Sludge thickening	4,190,909	1,356,862	2,216,045
Chlorination	889,166	828,845	812,324
Microscreen	---	2,388,640	2,017,394
Electrical and Instrumentation	4,991,556	4,991,556	5,557.500
Yard piping	3,993,245	3,993,245	4,446,000
Site preparation	6,588,854	6,588,854	7,335,900
Land acquisition and fees	695,989	696,221	693,835
TOTAL CAPITAL COST	$56,619,607	$49,415,863	$63,167,640
		¢/1000 gallons	
TOTAL AMORTIZATION COST	18.84	16.0	21.10
TOTAL O & M COST	11.80	6.60	8.80
TOTAL TREATMENT COST	30.64	23.0	29.90

Conclusions

Our results for the cost of treatment of ground refuse-sewage mixtures are at first glance at considerable variance to those of Metcalf & Eddy.[52] If one excludes land acquisition and site preparation, our calculations show an increase in capital cost from \$31.91 million to \$42.63 million, or by a factor of 1.33; whereas Metcalf & Eddy anticipated an increase from \$1.6 million to \$4.1 million, or by a factor of 2.5

There are several explanations for this discrepancy.. First, the Metcalf & Eddy estimates are for a facility of 1 mgd (3,785 m^3/day) whereas our estimates are for a 64 mgd (242,240 m^3/day) facility. Second, the Metcalf & Eddy estimate was based on a refuse concentration of 0.5 percent by weight. Indeed, our calculation for an 0.4 percent by weight addition of refuse, corresponding to a 4.5 lb/cap/day (2.04 Kg/cap/day) generation rate, shows an increase of 1.72, which approaches the Metcalf & Eddy figure.

The approach taken in our analyses might perhaps be questioned on the basis that the use of design relationships based on sewage inputs are not necessarily valid for ground refuse additions. Whilst conceding that this may well be so, we have at least used a rational quantitative basis for our inferences and cost estimates, which, surely, must be preferable to intuitive qualitative judgments.

SECTION VIII

SLUDGE HANDLING*

Introduction

Although the treatment plant simulations described in the previous section were judged adequate to determine overall treatment costs, a more detailed investigation into sludge handling was deemed necessary, because the unit operation routines in the treatment plant simulation model were operating at solids concentrations in excess of their original design. Perhaps the most important specific goal of the detailed study was to establish the unit cost of sludge processing and disposal. The cost of collection and disposal of residential refuse under existing management concepts lies in the range of $20 to $60 per ton; consequently, if the cost of just the sludge handling in a wet system is also $20 to $60 per ton (of dry solids), as would be expected on the basis of existing practice at sewage treatment plants, then the economic feasibility of the wet systems concept is questionable, even given that the transformation of solid waste to sludge solids is not 1 to 1.

It should be noted, however, that our efforts should be interpreted as only a preliminary effort to analyze a very complex problem, and will need to be extended considerably before even a pilot scale demonstration facility is contemplated. The major constraint limiting both the scope of the analysis and its accuracy was the exceptionally limited experimental evidence available to us. However, we are conficent that our predictions of total costs are entirely adequate for the primary purpose of the contract which is to establish the order of magnitude of cost for the wet systems concept as a whole, even if we have not been able to address the myriad of operational complexities in sufficient detail to make definitive judgments on process selection and operation.

Sludge Quantities

The major factor affecting the quantity of sludge produced at a treatment facility handling ground refuse is the per capita refuse generation rate. Other factors to be considered include sedimentation efficiency, the conversion of dissolved organic matter to settleable biomass and the per capita generation of sewage solids. In the case of an average raw refuse generation rate of 2.25 lb/cap/day (1.02 Kg/cap/day), the addition of ground refuse to the sewage will result in about a fifteenfold increase in the quantity of primary sludge. On the other hand, because of a very small increase in the BOD in the primary settler effluent due to the ground-refuse, the volume and dry solids content of the waste activated sludge will change much less. Under the same condition (2.25 lb/cap/day of raw refuse) there will be only a 45 percent increase of the quantity of waste-activated sludge, which is still in the range of variation exhibited by existing sewage treatment plants. The quantity and the concentration of the mixture of primary and waste-activated sludge is therefore affected primarily by variations in the primary sludge. The amount of dry solids of the sludge mixture of primary and waste-activated sludge in tons per year, as a function of population and refuse generation rate, is shown on Figure 8. The report by Kos et al.[21], should be consulted for the derivation of these assertions.

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*Sludge Processing and Disposal is the subject of a separate report by Kos, Joyce and Meier, (Ref. 21).

In order to dramatize the impact of the ground refuse upon the sludge handling, quantity-concentration flow diagrams of a conventional sewage treatment plant and a sewage treatment plant handling ground refuse in addition to sewage were constructed. Assuming a sewage generation rate of 100 gal/cap/day (378.5 ℓ/cap/day), Figure 9 shows the consequent flows (in the percentages of the incoming sewage) and their solids concentrations. Similarly, Figure 10 shows the flow diagram of a treatment plant handling 100 gal/cap/day of sewage plus 2.25 lb/cap/day of ground refuse.

Comparison of these diagrams reveals the magnitude of the impact of ground refuse additions. For example, the volumetric flow rate of vacuum filter cake shows an increase from 0.04 to 0.34 percent of the influent volume. This implies that at a 10 mgd (37,850 cu m/day) facility, the filter cake would increase from 4,000 to 34,000 gal/day (15,140 to 128,690 ℓ/day). For the total raw refuse generation rates of 1.0, 2.25, or 4.5 lb/cap/day (0.454, 1.02, or 2.04 Kg/cap/day), a 2.5, 4.3 and 7.8-fold increase of sludge quantities must be expected. Using a dry solids basis (which is unaffected by concentration variations of the sludge) rather than a volumetric measure, the introduction of ground refuse into the sewage under the same conditions as above will result in the 4.7, 9.3 and 17.5-fold increase of dry sludge solids, respectively. Note that the difference between the volumetric and dry solids increases are due to the increase in concentration of the primary-secondary mixture. In summary, the sludge handling facilities of a sewage treatment plant handling an average 2.25 lb/cap/day (1.02 Kg/cap/day) of ground refuse will correspond to a conventional treatment plant handling a population that is approximately nine times larger.

Sludge Quality

Information on the quality parameters of ground refuse sludges is very limited, consisting of studies conducted by Metcalf & Eddy as part of the original Foster-Miller work, and isolated information from a few studies whose focus was energy production from solid waste. In particular, there appear to be no measurements of quantitative sludge parameters such as coefficient of compressibility or specific resistance, both of obvious importance to assessments of dewatering characteristics. This is an area that is in urgent need of more detailed investigation if the wet systems concept is to be further pursued.

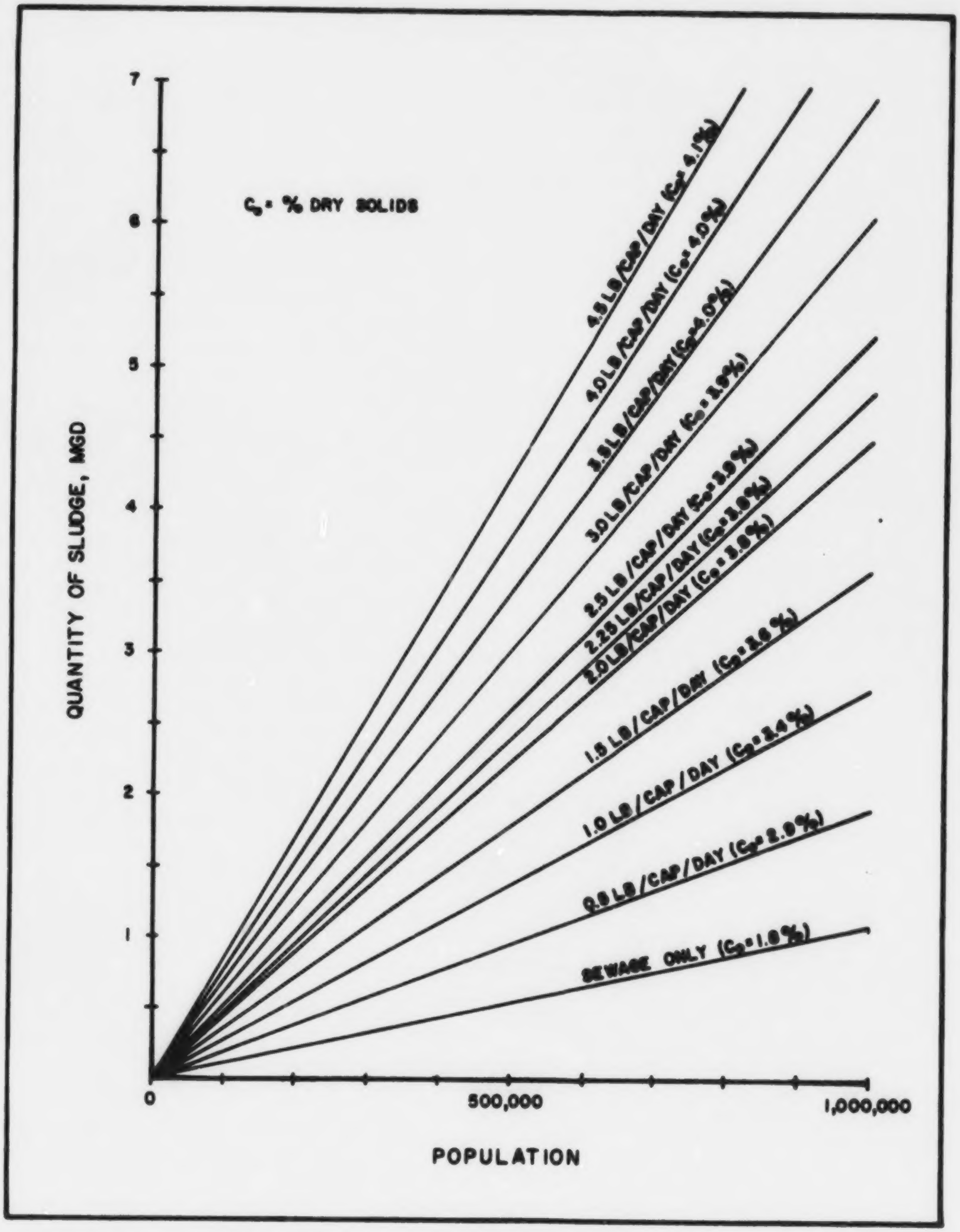

Figure 8: Dry Sludge Solids as a Function of Population Size and Refuse Generation

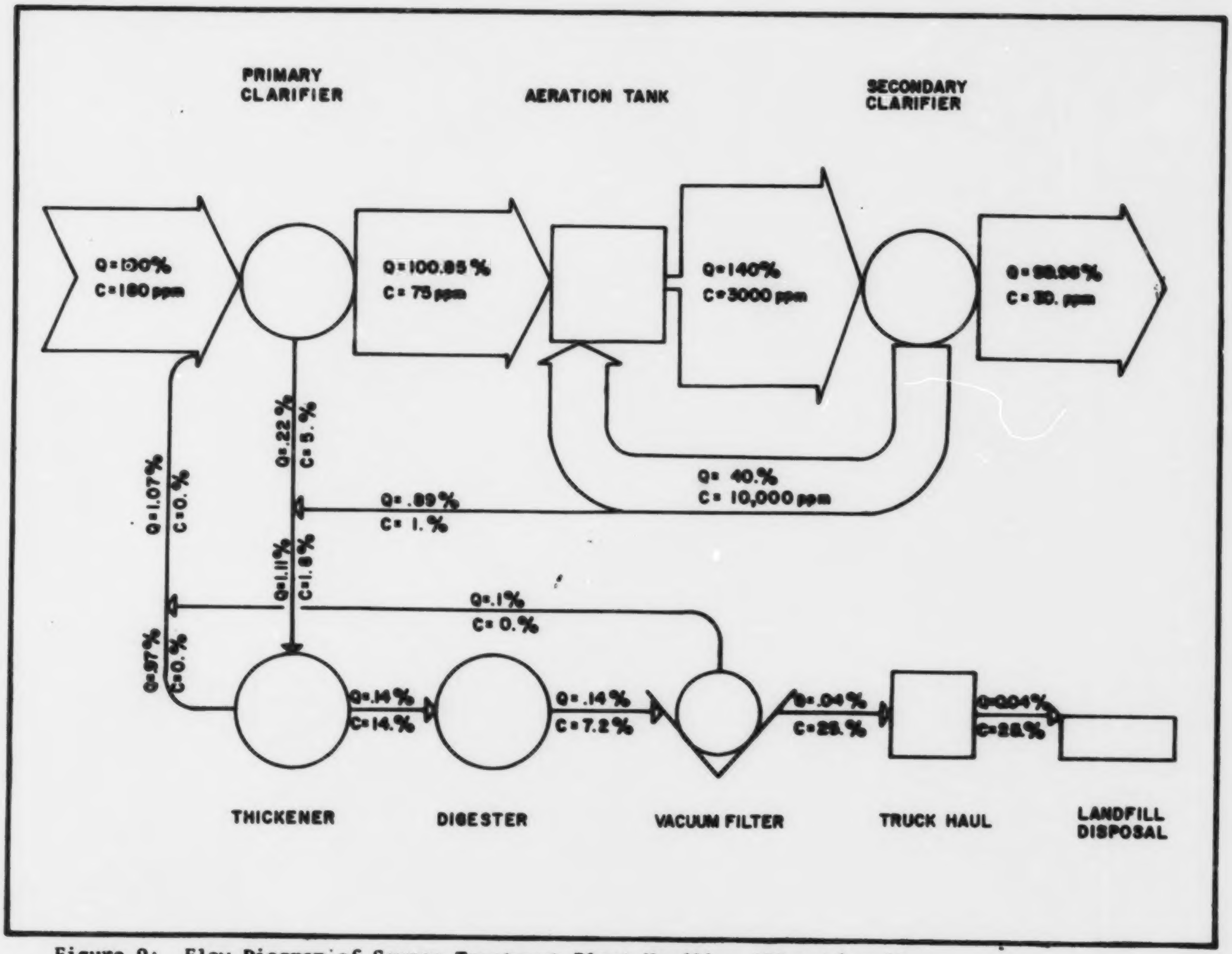
PRIMARY CLARIFIER
AERATION TANK
SECONDARY CLARIFIER
Q=100%
C=180 ppm
Q=100.85%
C=75 ppm
Q=140%
C=3000 ppm
Q=98.96%
C=30. ppm
Q=.22%
C=5.%
Q=40.%
C=10,000 ppm
Q=.89%
C=1.%
Q=1.07%
C=0.%
Q=1.11%
C=1.8%
Q=.1%
C=0.%
Q=.97%
C=0.%
Q=.14%
C=14.%
Q=.14%
C=7.2%
Q=.04%
C=28.%
Q=0.04%
C=28%
THICKENER
DIGESTER
VACUUM FILTER
TRUCK HAUL
LANDFILL DISPOSAL

Figure 9: Flow Diagram of Sewage Treatment Plant Handling 100 gal/cap/day

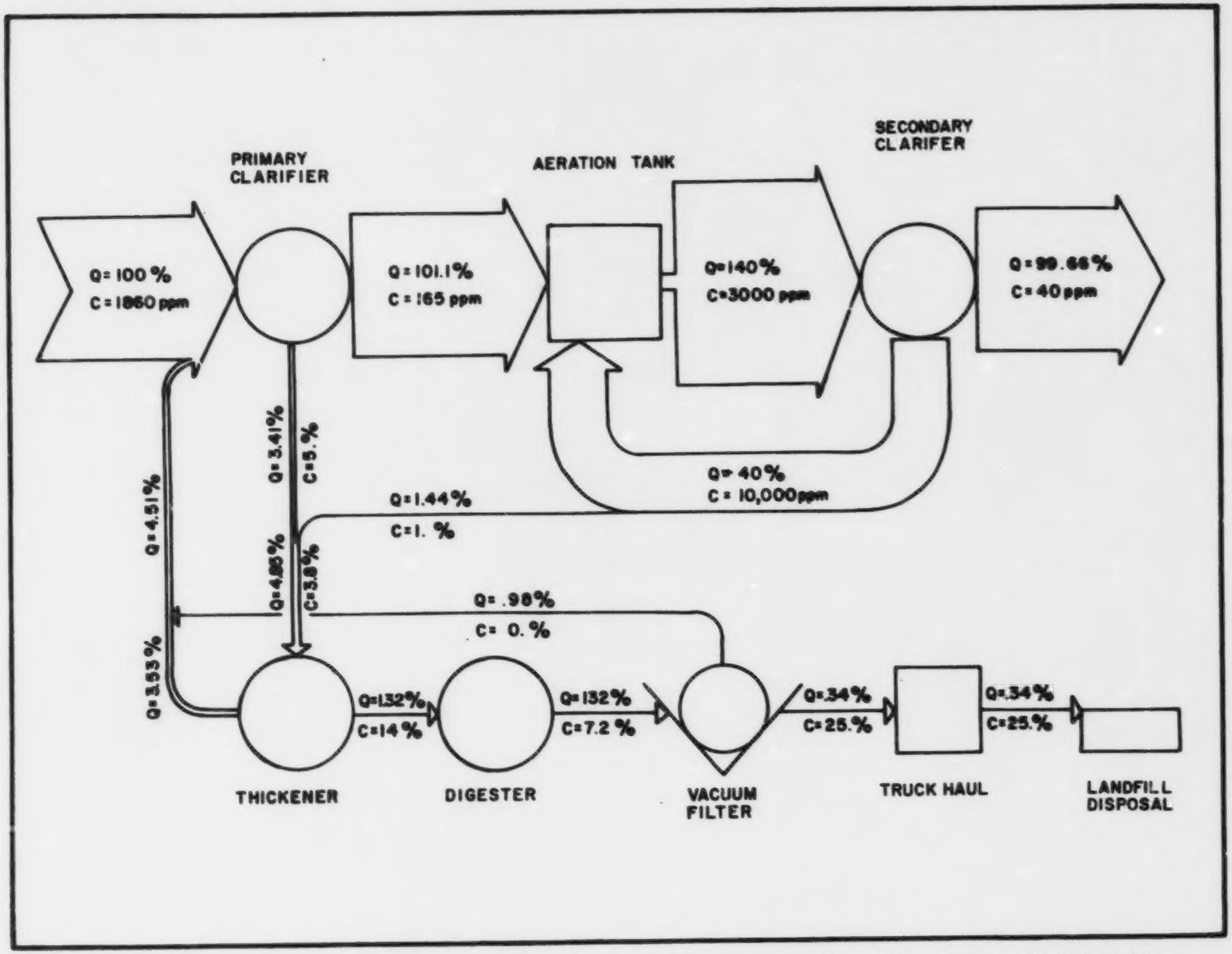
PRIMARY CLARIFIER
AERATION TANK
SECONDARY CLARIFER
Q= 100 %
C = 1860 ppm
Q = 101.1%
C = 165 ppm
Q=140%
C=3000 ppm
Q=99.66%
C=40 ppm
Q= 40%
C = 10,000 ppm
Q=1.44%
C=1. %
Q=3.41%
C=5.%
Q=4.51%
Q=4.85%
C=3.8%
Q= .98%
C= 0.%
Q=3.53%
Q=1.32%
C=14%
Q=1.32%
C=7.2 %
Q=.34%
C=25.%
Q=.34%
C=25.%
THICKENER
DIGESTER
VACUUM FILTER
TRUCK HAUL
LANDFILL DISPOSAL

Figure 10: Flow Diagram of Sewage Treatment Plant Handling 100 gal/cap/day plus 2.25 lb/cap/day

Raw Sludge. Metcalf & Eddy[53] found that 1-hour settling of ground refuse in sewage produced a sludge of about 5 percent solids content. Much of the suspended solids, consisting mainly of paper products, did not settle, or only very slowly. However, the dewatering characeristics of this primary sludge (including the floatables) appeared to be good. Metcalf & Eddy tested three devices for dewatering the primary sludge produced by adding ground refuse to sewage, although tap water rather than sewage was used in these laboratory tests: a Smith and Loveless sludge concentrator, a Komline-Sanderson vacuum filter, and a Bird centrifuge. All three devices worked well, and neither the vacuum filter nor the centrifuge required addition of chemicals. For all three methods tested, they obtained a sludge cake of at least 25 percent solids content. The yield of a vacuum filter was at least 8 pounds per square foot per hour (39.06 Kgs/sq.m/hr), and Metcalf & Eddy judged that it could serve as the only dewatering unit.

The specific resistance and coefficient of compressibility of sludge are quantitative measures of its dewatering characteristics, but unfortunately Metcalf & Eddy did not evaluate them, and these are as yet unknown for the sludges obtained when ground refuse is added to sewage. The vacuum filtration yield reported by Metcalf and Eddy is in the range of expected yields of chemically conditioned primary sludge, and therefore the dewatering characteristics of primary sludge of a sewage treatment plant handling ground refuse will be considered to be the same as those of chemically conditioned primary sludges. This assumption is not unreasonable in the light of some recent experiments at the University of Texas by Carden and Malina[54] on the efficacy of pulped newsprint as a sludge conditioner. Pulp additions of about 100 to 125 percent of the weight of sludge solids were found to reduce the specific resistance of activated sludge to levels comparable to the optimal levels attained with ferric chloride or cationic polymers. It was noted that the conditioning effect of the newspaper pulp increased as the solids content of the activated sludge increased, and it was concluded that the chemical conditioners could be replaced by the paper pulp with essentially similar results. This means that we might expect paper fiber in the primary sludge to act as a conditioner for the activated sludge fraction.

There is no information on the thickening of the sludge that would be generated in a sewage treatment plant handling refuse. On the basis of the apparent similarity between filtration characteristics of the primary sludge at sewage treatment plants handling ground refuse and between ordinary chemically conditioned primary sludge, the thickening of these two kinds of sludges may also be assumed to be similar.

The remaining problem is the effect of adding a small portion of secondary treatment sludge upon the character of primary sludge. It is usually reported that the specific resistance or vacuum filter yield is less than for the mixture of primary and activated sludges than for primary sludge alone. On the basis of the laboratory thickening experiments, Konicek, Kos and Pardus[55] found, however, that the addition of activated sludge to primary sludge in the ratio occurring in a conventional secondary treatment plant had little significant effect on the thickening of primary sludge.

In light of these facts and because of the very high ratio of primary to waste-activated sludge at the treatment plant handling refuse, the addition of waste-activated sludge to the primary sludge will most likely have little or no effect upon the thickening and filtration characteristics of the primary sludge. Consequently, the characteristics observed for primary sludge by Metcalf & Eddy may be assumed to hold also for the primary-secondary mixture.

Digested Sludge. Pfeffer, who used the filter-leaf technique, found that the residue from digestion of refuse-sewage sludge dewatered very easily, without addition of conditioners.[56] This is in contradiction to the findings of Wise,[57] who found that the digester residue dewatered only with difficulty. However, the reactor solids concentrations used by Wise were below 2 percent, whereas Pfeffer's were generally above 6 percent. In the absence of a comprehensive study of the residue after digestion of refuse-sewage sludges, we must assume that the quality of the digested refuse-sewage sludges will be the same as that of the ordinary digested sludge. Although it is recognized that this assumption is subject to question, it is unavoidable in the absence of any actual data. But insofar as this asssumtion does imply a need for chemical conditioner additions prior to dewatering, it is probably conservative.

Analysis

As in the case of treatment, mathematical modelling and simulation was chosen as the method by which the answers to some of the questions relating to cost would be examined. In order to keep the simulation efforts within reasonable time and cost limits, four likely process configurations were selected in advance, all purposely involving only traditional technologies. This was justified on the basis that cost functions for many of the newer processes such as wet oxidation or pyrolysis are not presently available in the absence of a sufficiently widespread practical experience. But more importantly, perhaps, is the inability to make predictions of process performance. Whilst it is relatively easy to predict the consequences of ground refuse addition to, say, thickening or vacuum filtration, in the absence of even laboratory data, similar predictions for the more sophisticated technologies would be quite speculative. Indeed, we are already at the limit of reasonable prediction by including digestion as one of the alternatives.

This is in no way to imply that these technologies are inferior or even more expensive than the traditional ones to which we have addressed our detailed analysis. Rather, our goal is to establish a reasonably accurate picture of the costs involved in the handling and disposal of ground refuse sludges, in order that the economics of the entire wet systems concept can be established.

Considerations in the Selection of Alternative Process Configurations. Because of the dramatic increase in the ratio of primary to secondary sludge at a facility accepting ground refuse, it was earlier concluded that the addition of secondary sludge to the very much larger quantity of primary sludge would not alter the latter's physical-chemical characteristics. Consequently, separate treatment of these sludges does not appear reasonable. Many new treatment plants provide different treatment processes for primary and secondary sludge streams; as noted in an earlier chapter, the planned additions to the treatment facilities in the Springfield area will use air floatation thickening for the waste-activated sludge and gravity thickening for the primary. It is questionable whether such a configuration would be beneficial for handling ground refuse sludges, especially from the viewpoint of scale economies. Therefore, the initial operation for all process configurations is a mixing of the two sludge streams.

Because activated sludge is currently the most widespread secondary treatment method, we restricted our focus to that particular source of secondary sludge. The assumption of a 1 percent solids concentration of the waste activated sludge may well be questioned, but in view of the wide diversity of concentrations encountered in practice, and the fact that the much higher primary to secondary sludge ratio tends to make subsequent computations relatively insensitive to the assumed secondary concentration, the 1 percent figure does not appear unreasonable.

The impact of the addition of advanced waste treatment processes to a secondary treatment plant must doubtless be considered in the very near future. And while the sludge production varies considerably with the process selected, there is as yet insufficient information upon which to base a rational choice of advanced waste treatment at a plant handling ground refuse. Consequently, we may rationalize our omission of advanced treatment sludges not only on the basis that the quantity involved would be small in comparison to that from the ground refuse (that will settle as primary sludge), but also that the uncertainties involved are still too great for the selection of any one process to have real meaning.

Three of the process configurations chosen for study are illustrated on Figures 11, 12, and 13. The fourth configuration, including both anaerobic digestion and incineration was also examined, but was found to be quite uneconomic.

Model Representation and Cost Functions. Mathematical models for all of the unit operations considered were constructed for inclusion into the computer simulation model. Most of the cost functions built into the individual unit operation models were from the study conducted for EPA by Black & Veatch,[58] whereas the design relationships were taken from a variety of published sources or derived by the writers. Details of the model representations for each of the unit operations considered can be found in Chapter III of Kos *et al.*[21]

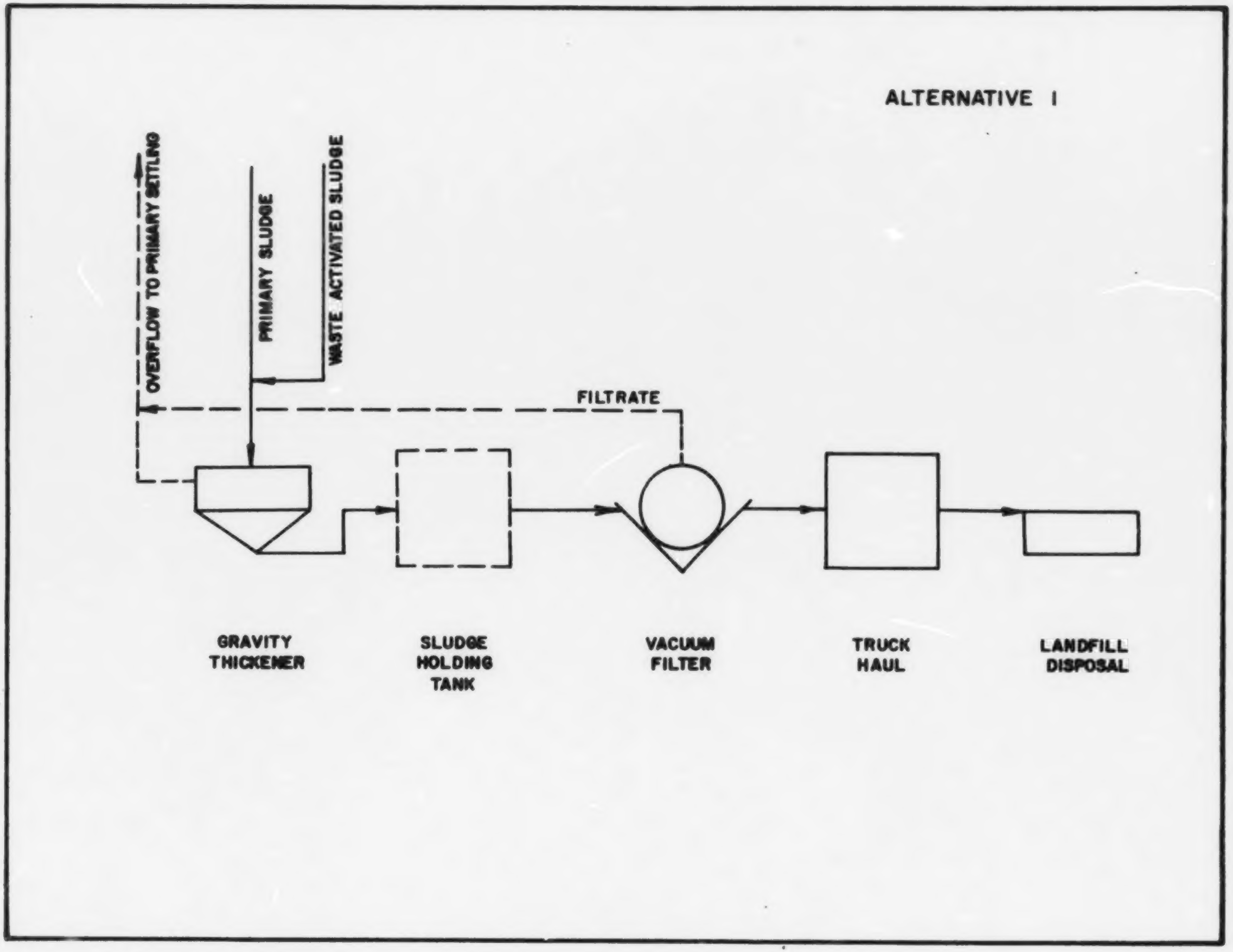
ALTERNATIVE 1
OVERFLOW TO PRIMARY SETTLING
PRIMARY SLUDGE
WASTE ACTIVATED SLUDGE
FILTRATE
GRAVITY THICKENER
SLUDGE HOLDING TANK
VACUUM FILTER
TRUCK HAUL
LANDFILL DISPOSAL

Figure 11: Sludge Handling, Alternative 1

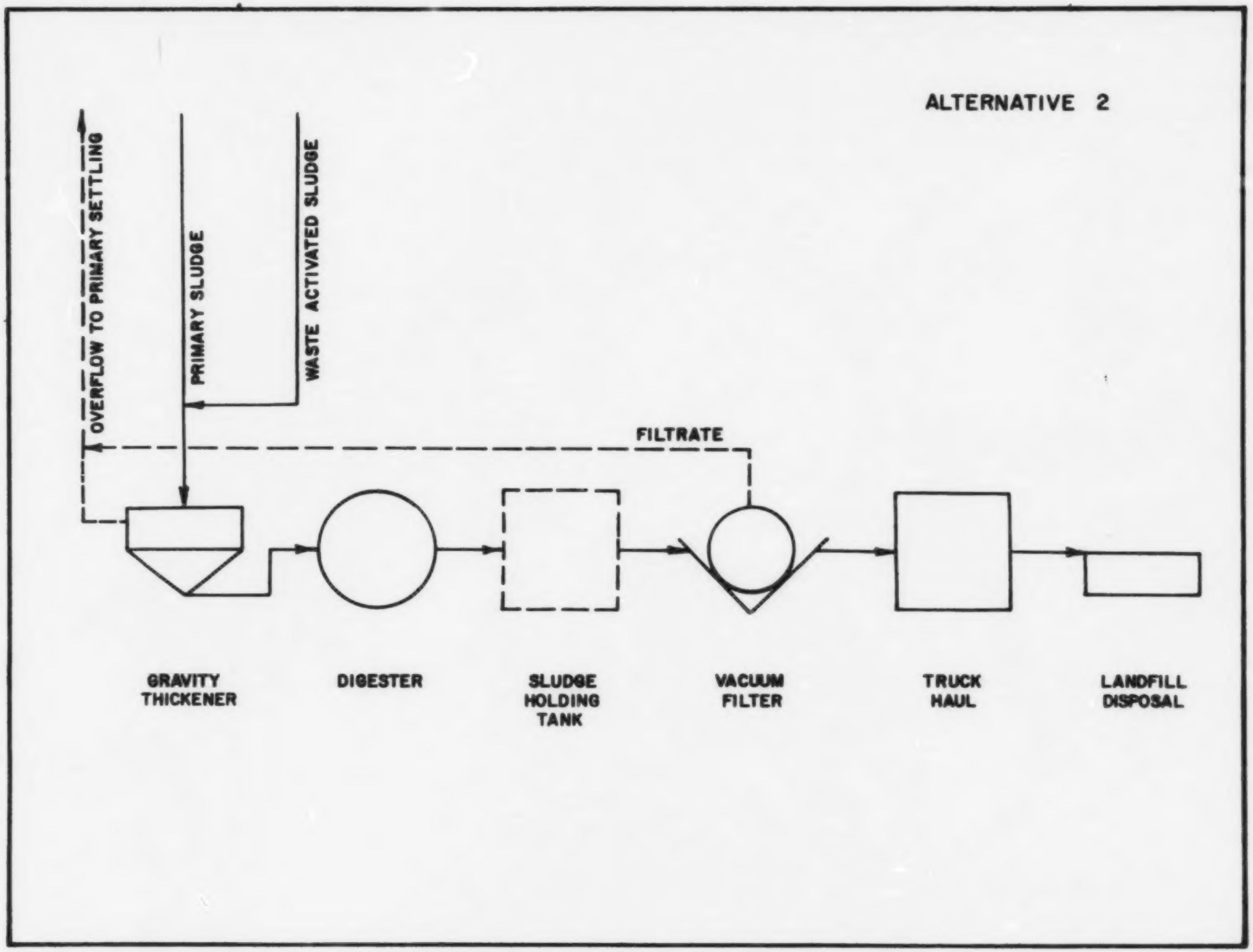
ALTERNATIVE 2
OVERFLOW TO PRIMARY SETTLING
PRIMARY SLUDGE
WASTE ACTIVATED SLUDGE
FILTRATE
GRAVITY THICKENER
DIGESTER
SLUDGE HOLDING TANK
VACUUM FILTER
TRUCK HAUL
LANDFILL DISPOSAL

Figure 12: Sludge Handling, Alternative 2

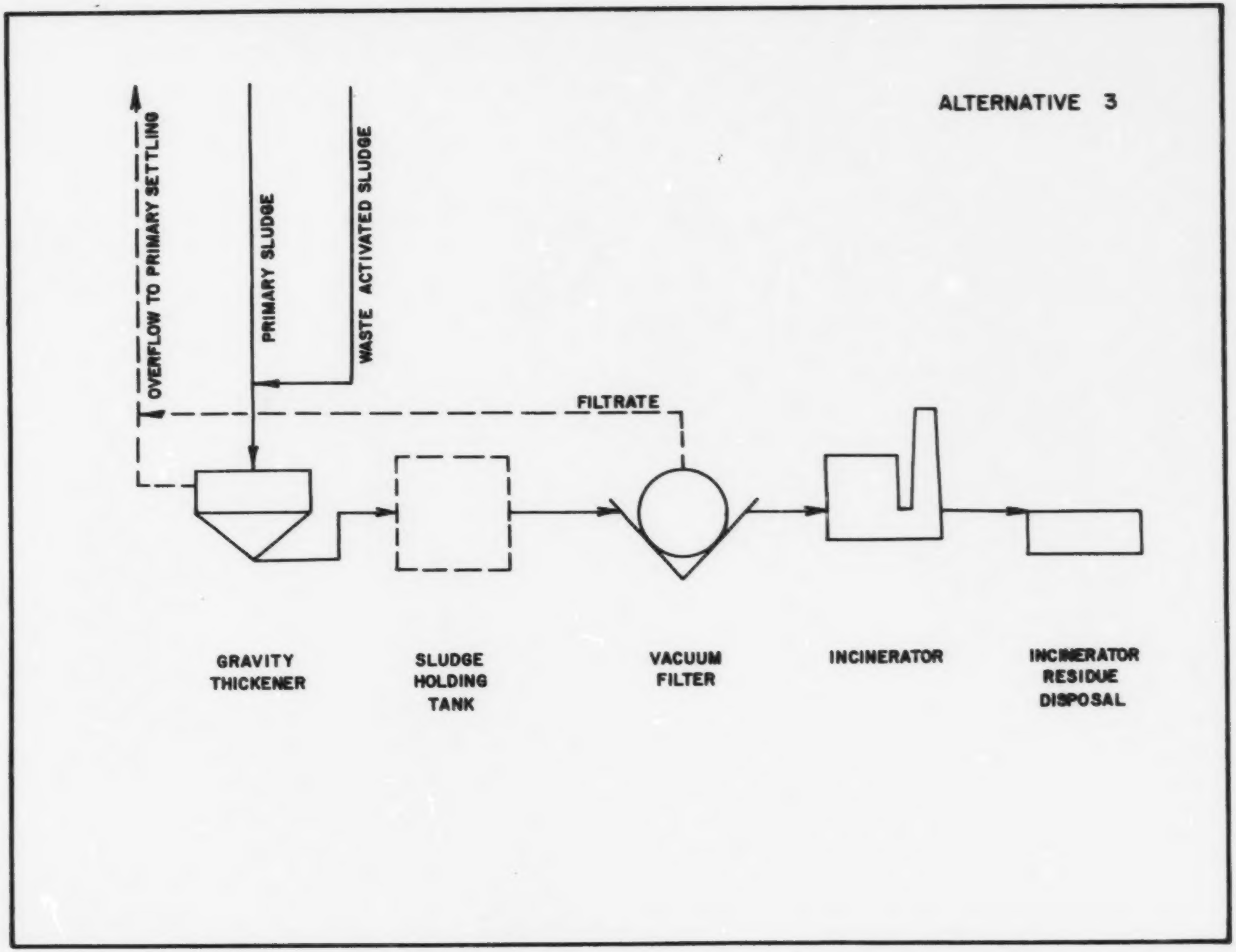
ALTERNATIVE 3
OVERFLOW TO PRIMARY SETTLING
PRIMARY SLUDGE
WASTE ACTIVATED SLUDGE
FILTRATE
GRAVITY THICKENER
SLUDGE HOLDING TANK
VACUUM FILTER
INCINERATOR
INCINERATOR RESIDUE DISPOSAL

Figure 13: Sludge Handling, Alternative 3

The simulation model was then run for each process configuration under a wide range of operating parameters, sludge solids concentrations, size of facility, input solids generation rates, and the details of the results plotted and analyzed in detail in Chapter IV of Kos et al.[21]

Comparison of Alternative Process Configurations. The costs of the three feasible process configurations are summarized on Figure 14. Alternative 1, involving thickening, vacuum filtration and land disposal, is the indicated choice, with a cost of between $10 - $15 per ton ($11.02 - $16.53 per Kkg) of dry solids for facilities serving in excess of 100,000 population. If a digester is added (Alternative 2), total costs will be about $5/ton ($5.51/Kkg) dry solids higher, an increase that is almost offset by the value of the digester gas produced. Under the assumed conditions of a landfill at 10 miles (16 km) distance, incineration as a means of disposal (Alternative 3) is shown to be another $4/ton ($4.41/Kkg) more expensive. Digestion together with incineration was dismissed as an economically infeasible alternative.

Tables 8, 9, and 10 summarize the costs of these three alternatives as a function of population size and per capita refuse generation rate, with an indication of the corresponding cost for a facility treating only sewage sludge. It is quite evident that the unit cost of handling sludge at a facility handling ground refuse is substantially lower than if only sewage sludge were handled. This is due to the economies of scale resulting from larger absolute quantities involved, and the very different physical nature of the sludge to be dewatered and disposed.

Optimal Solids Concentrations. Our analyses show that in those cases where the total cost is sensitive to solids concentration, such as those process configurations involving digesters, an optimum appears to lie in the vicinity of 14 percent solids. If this appears high, as it doubtless does in comparison to solids concentrations encountered at existing treatment plants, one should be reminded of the drastically different nature of the sludge involved. A feed of such a high solids concentration is essential whenever digesters are used, as the cost of digester capacity would otherwise be prohibitive. Where digesters are not used, the decrease of vacuum filtration cost resulting from higher solids concentration is balanced by the increase in the cost required to thicken the sludge to the higher concentration, and no optimum solids concentration can be identified.

Digestion. Our calculations show that the cost of anaerobic digestion is somewhat higher than the resultant value of methane produced, and that the cost of process configurations using landfill for ultimate disposal is insensitive to whether or not digestion is included, given a methane value of $0.80 per 1000 cu ft ($28.50/100 cu m). A lesser methane value would make the use of digesters unlikely, whereas an increased value, or consideration of the more intangible benefits of increasing energy supplies given the current energy shortages, such as benefits to the balance of payments, would tend to make digestion more attractive. All this, of

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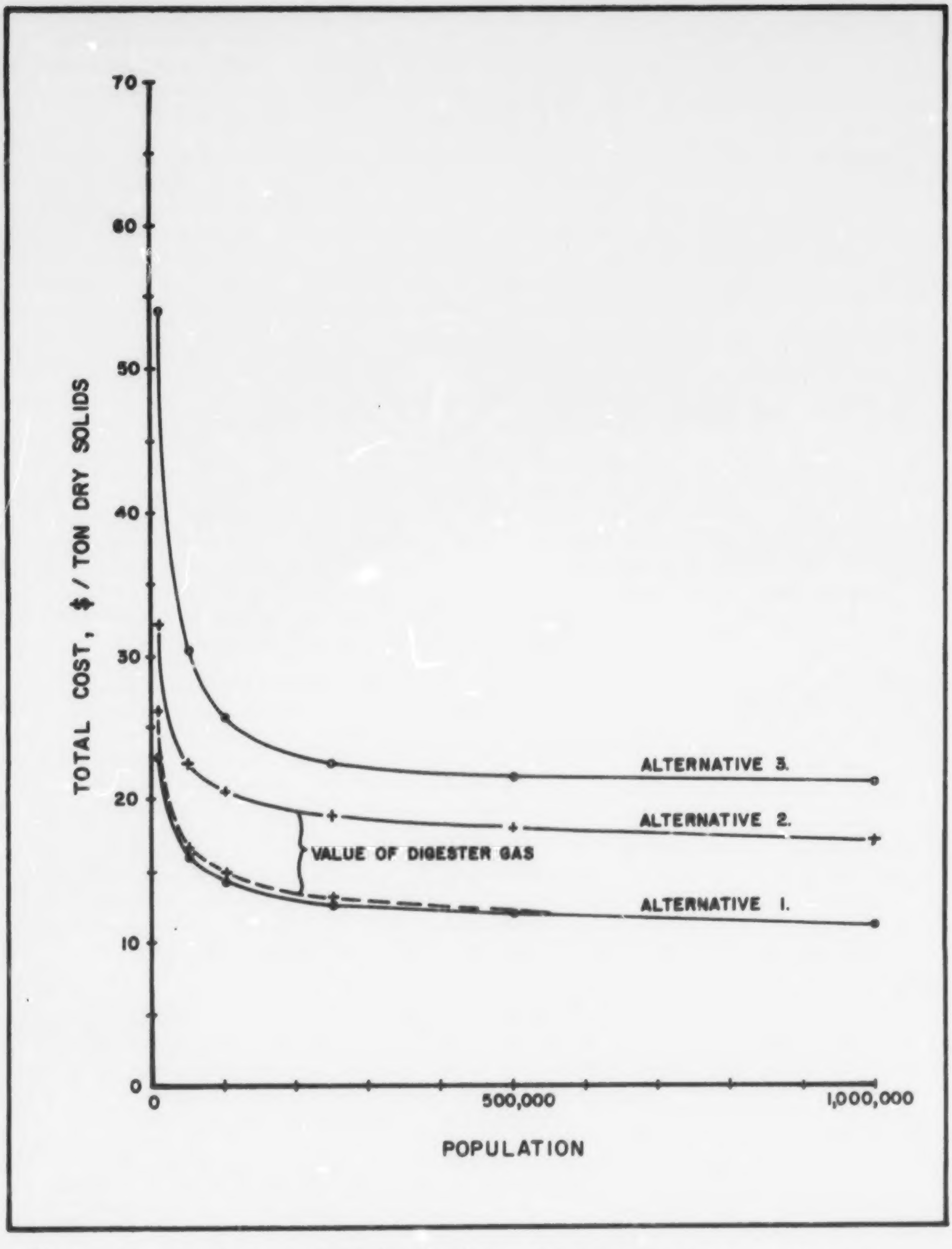

Figure 14: Total Cost of Sludge Handling (Alternative 1, 2 and 3) as a Function of Population; for Average Refuse Generation Rate of 2.25 lb/cap/day

Table 8; Total Cost of Sludge Handling (Alternative 1) in $/ton Dry Solids for Various Populations and Various Raw Refuse Generation Rates

Raw Refuse Generation Rate lb/cap/day	POPULATION					
	10,000	50,000	100,000	250,000	500,000	1,000,000
0 (Sewage Sludge Only)	80.75	41.96	34.23	27.68	23.98	21.03
0.5	39.16	22.79	19.59	16.58	14,95	13.69
1.0	30.35	19.21	16.72	14.47	13.27	12.36
2.0	23.92	16.26	14.55	12.97	12.10	11.47
2.25	23.04	15.99	14.31	12.76	11.95	11.35
3.0	21.13	15.07	13.66	12.30	11.60	11.11
4.0	19.51	14.37	13.09	11.93	11.33	10.92

Table 9: Total Cost of Sludge Handling (Alternative 2) in $/ton Dry Solids for Various Populations and Various Raw Refuse Generation Rates

Raw Refuse Generation Rate lb/cap/day	POPULATION					
	10,000	50,000	100,000	250,000	500,000	1,000,000
0 (Sewage Sludge only)	134.58	53.94	43.25	34.72	30.57	27.32
0.5	56.30	30.95	26.52	22.93	21.09	19.74
1.0	42.71	26.31	23.20	20.68	19.34	18.31
2.0	33.46	22.93	20.87	19.07	18.07	17.20
2.25	32.25	22.47	20.54	18.84	17.89	17.03
3.0	29.64	21.58	19.86	18.36	17.48	16.61
4.0	27.47	20.70	19.27	17.94	17.09	16.20

Table 10: Total Cost of Sludge Handling (Alternative 3) in $/ton Dry Solids for Various Populations and Various Raw Refuse Generation Rates

Raw Refuse Generation Rate lb/cap/day	POPULATION					
	10,000	50,000	100,000	250,000	500,000	1,000,000
0 (Sewage Sludge only)	265.74	87.67	64.15	46.28	37.96	32.36
0.5	107.61	44.47	37.14	28.94	25.30	24.04
1.0	77.88	38.29	30.99	25.24	22.94	22.05
2.0	56.89	31.27	26.35	22.75	21.89	21.26
2.25	54.08	30.30	25.72	22.44	21.64	21.04
3.0	48.01	28.17	24.37	22.56	21.45	20.77
4.0	42.92	26.37	23.29	21.80	21.20	20.64

course, is contingent on the assumption that anaerobic digestion is in fact feasible, an assumption that is yet to be convincingly demonstrated. As noted in a recent paper on management aspects of methane production from solid wastes,[59] reliability of supply will play a crucial role in successful marketing of the recovered energy. But skeptics who cite the traditional unreliability of sewage treatment plant digesters as a key argument against digesters might be reminded that sophisticated physical-chemical sludge treatment methods, such as the wet oxidation processes currently very much in favor, are surely at least as dependent on trained and experienced operator personnel as are digesters.

The constraints of this study have not allowed as detailed an investigation of the trade-offs in digestion as will be necessary if digestion were to be seriously considered in an actual implementation. In particular, the physical characteristics of the digesting sludge require identification if factors such as mixing cost are to be adequately analyzed. Other areas not fully explored include the impact of climate (which has a substantial impact on heating costs), the relationship between detention time and reliability, the impact of recycling the digester supernatant to the secondary treatment stages, and nutrient addition. A comprehensive study focussed on a complete economic model of digesters would thus be recommended as a segment of further investigations into sludge handling.

Disposal Method. Of the two disposal methods examined by our studies, incineration is shown to be preferable to direct landfill disposal only if the distance to the landfill exceeds 45 miles (72.4 km). The magnitude of this critical distance, of course, is dependent on many contributory factors, and would tend to increase as the cost of air pollution control equipment drives up the cost of incineration, and would tend to decrease with increased land or unit transportation costs. But, given the political realities as they presently exist, it is questionable whether a city that cannot find a landfill site within its own city limits or with an immediately adjacent community could ever use a more distant landfill, regardless of cost. Thus, all that can usefully be concluded in general terms is that both alternatives are technically feasible, and that their cost is of comparable magnitude. Indeed, it would appear that the wet systems concept offers little significant advantage over conventional practice with respect to the ultimate disposal problem. And although advanced technologies such as pyrolysis might offer a solution, such technologies are not dependent on a wet collection method.

SECTION IX

ENVIRONMENTAL AND SOCIOECONOMIC IMPACTS*

Environmental Impact

The conclusions with respect to environmental impact are necessarily qualitative, rather than quantitative, and we have not attempted to attach dollar values to the environmental costs and benefits identified. And although the conclusion of the analysis is that the net impact will probably be beneficial, there are one or two potentially serious impacts which cannot yet be assessed due to lack of data. Thus, even if accepted methodologies were available for the dollar measurement of intangible environmental impacts, inclusion of these dollar values into the engineering cost comparisons would be presently quite premature.

One of the difficulties in assessing the environmental impact of the wet systems concept is the need to assess the totality of environmental quality. Thus, air quality might improve at the same time that water quality might diminish, yet there is no accepted way to effect the trade-off in even qualitative terms. Is one additional unit of BOD in a river worth the decrease of one unit of particulate emissions? Clearly, such questions can only be answered by reference to a specific situation and perspective, and the goals and priorities that govern the evaluation.

Air Quality

Air Pollution from Conventional Practice. There are two major potential sources of air pollution from conventional refuse collection and disposal practice: the emissions from collection trucks, significant especially in the central city, and emissions from incineration or illegal open burning in dumps.

With respect to emissions from collection trucks, the conditions under which they must operate make for very unfavorable emission conditions. Internal combustion engines burn fuel most efficiently at relatively constant speeds, and the amount of unburned fuel increases sharply when a motor vehicle is accelerated or decelerated. Emissions of hydrocarbons, carbon monoxide and particulates may be 50 to 100 percent greater for average speeds less than 10 miles per hour (mph) as compared to 30-35 mph, and especially idling, acceleration and deceleration are associated with high emission levels.

In central urban areas where distance traveled by collection trucks is slight compared to time spent, the contribution to urban air pollution from the collection fleet may be in excess of what it would appear to be if total miles traveled is used as a measure. For example, in the Springfield study area, the miles of travel by the 21 collection trucks may be conservatively estimated at 500 miles by map measurement. For each truck, the measured distance included length of the assigned route plus allowance for two trips to the landfill site. Since vehicular travel in Springfield amounts tc over 1.1 million miles per day[60] this 500 miles is negligible. However, considering the substantial time spent idling and the fact that emissions during idling and speed changes may be greater than cruising emissions by factors of 2 to 6, the total contribution of the fleet to automobile air pollution may be on the order of 0.5 percent of the total.[61]

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*See Meier, Kuhner, and Bolton, (Ref. 22), Chapters VI, VII and VIII for detailed discussions.

Although neither refuse incineration nor open burning occurs in the Springfield area, the impact of such practices elsewhere is well recognized. The costs of municipal refuse incineration are expected by many to double as enforcement of emission standards becomes widespread,[62] and the impact of open burning was demonstrated all too tragically by the fatalities of a recent multiple car crash on the New Jersey turnpike reportedly caused by aggravation of fog conditions by smoke from a nearby dump.[63]

The Impact of Wet Systems on Air Pollution. Introduction of wet systems disposal for residential refuse would greatly decrease the number of refuse trucks on the streets. Collection by vehicle could be eliminated for all but those crews necessary to handle the nongrindable fraction of the refuse. Estimations discussed previously show that between three and four pickups per year will be required to handle nongrindables, requiring at most four collection trucks. Assuming identical unit emission levels would imply that air pollution from collection truck exhausts would be decreased 75 percent from present levels. A corresponding decrease should be experienced in support vehicle travel, such as vehicles operated by foremen and other supervisory personnel. On the other hand, it is expected that bulky item collections, currently involving two crews a day in Springfield, will require more vehicles for operations in conjunction with wet systems implementation, perhaps doubling in size.

Wet systems collection would virtually eliminate air pollution from on-site burning. The availability and ease of disposal of rubbish into the grinder should drastically decrease the incentive for on-site burning, making the enforcement of existing ordinances a more feasible proposition. But since it is primarily garden waste that continues to present incentives for on-site incineration in residential areas, the practical feasibility of having to carry such wastes into the house and to the basement grinder location is somewhat questionable. Nevertheless, immediate removal of such wastes by grinding may well offset this apparent inconvenience.

Because the wet system would landfill refuse in the form of a sludge that may have 70 percent moisture or more, opportunities for open burning are clearly diminished relative to filling raw refuse. To the extent that the refuse sludge would be incinerated rather than landfilled, an additional source of pollutant emissions might be created; but there is no reason to assume that control of emissions at incinerators burning sludge is more difficult or costly than control at incinerators burning raw refuse.

Noise Quality

Noise from Conventional Refuse Collection Practices. Collection vehicles generate noise from the truck motor, the compaction mechanism and the crew during the loading process. Solid waste collection trucks travel their routes rarely at more than walking speed, and high sound levels are associated with both stopping, due to the "sigh" of air brakes, and starting, due to revving the motor as the clutch is released. The truck motor must be revved during movement from stop to stop and during the compaction cycle. This produces a loud, low frequency sound of varying length in the first case, of approximately 30 seconds duration in the latter, and sound levels of 90 dBA or higher depending on the type and condition of the truck. When the motor is engaged for compaction, a second source of sound is added to the motor noise. This comes from the compaction mechanism itself and sounds associated with the compression of loose rubbish. Although specific references are not available, it may be that higher estimates of noise production from collection operations found in the literature of 100-110 dBA may be associated with this peak output level.[64]

The noise resulting from the banging and clanging of the rubbish cans while being emptied may also be quite severe. This occurs not only when the collectors are carrying and emptying the containers, but also earlier in the morning when residents are bringing their cans to the curbside. Large steel drums tend to be more offensive since they are often too heavy for the collectors to lift and so are dragged out to the truck causing the high frequency rasping of metal against pavement. They are then banged against the hopper lip to assist in emptying. Less noise is produced if rubber, plastic or fiber containers are used instead of galvanized metal. Plastic and paper bags can be carried or dragged and loaded with little or no noise.

It should be pointed out, however, that the annoyance associated with a particular noise level is closely related to its duration, and thus the aforementioned impacts are not necessarily as great a nuisance as might be supposed. Nevertheless, a substantial proportion of complaints under newly introduced noise ordinances concern refuse collection,[65] and efforts are now underway for the promolgation and enforcement of federal noise emission standards for collection vehicles.

Observations in the Study Area. In the Springfield, Massachusetts study area, several different trucks operated by the Division of Solid Waste, of the Department of Public Works were studied during our route surveys. One type of truck, a screw compactor model of German manufacture, was significantly different from all other models regarding noise level production. The compaction mechanism in this truck is a cylinder in which a corkscrew shaped blade turns continuously. Since compaction is continuous, the truck motor is constantly idling at a high rate. The blade gradually forces the waste material deeper into the cylinder, compacting the rubbish with new rubbish as it is loaded in. This continuous circular path of the rubbish against the corkscrew, cylinder walls, and breaker blade in the truck causes a great deal of noise as the material is smashed and splintered into smaller pieces. Glass and metal pieces are notably noisy as they fall by force of gravity from the top of the cylinder.

Conversations with several Springfield residents living on routes serviced by the screw compactor trucks showed the people were aware of the increased noise from this type truck. One gentlemen remarked that he had not complained because the truck was faster during loading than others and so the noise was of a more temporary nature.[66] This was a valid point since the collectors do not have to halt loading operations for a compaction cycle. This interview also verified the tendency of people noted earlier to discount disturbing noise if it is temporary. The majority of collection trucks in Springfield are rear loading hydraulic compactors of American manufacture, which are relatively quiet while idling. We observed that at every third stop a compaction cycle was necessary, at which time the truck motor is speeded up and the compaction mechanism is engaged. As noted above, the two loudest sources are thus operative simultaneously.

Impact of Wet Systems on Noise from Conventional Collection Vehicles. Since wet systems collection will require vehicular collection only of nongrindables, collection frequency will decline. With collection of refuse by vehicle decreased from once a week to an average of once every 16 weeks, the frequency of noise from collection vehicles would obviously decrease. In neighborhoods which may be near collection or disposal facilities, corresponding decreases in vehicle traffic could greatly lower the ambient noise level. Perhaps the most significant effect might be felt in dense urban areas where refuse collection contributes significantly to both noise levels and traffic congestion.

Wet systems will not of course affect noise levels when the trucks do collect in a neighborhood. In fact, because the frequency of collection would be much reduced, the presence of collection trucks might be much more noticeable.

Impact of the Wet System on Noise Levels in the Home. The major noise impact of the wet systems concept is that of increased noise levels in the home, and the household refuse grinder designed by Foster-Miller incorporates several noise reduction features.[67] It is a wet process grinder which reduces noise from the tumbling of loose and flyaway pieces of refuse in the hopper. The grinder as designed is supported on an elastomer vibration isolation pad. Additionally, the hopper and top of the device are coated with a sound absorbing material to reduce grinding noise. In fact, noise levels might be less than from garbage grinders, since the latter has no lid to mask the grinding noise, and, for convenience of installation in sink, the motor and mountings may not be shrouded or mounted on dampers. Foster-Miller estimates their appliance as designed would be slightly more noisy in operation than a kitchen dishwasher,[68] with the noise levels estimated to lie in the range of 65-75 dBA.

Since it is recommended the grinder be placed in the basement or other service area, the operator would be probably the only person receiving direct effects of the noise. The operator's exposure to the noise would most likely be infrequent and of brief duration. This moderates the relatively high noise level which might be encountered. The direct effects during operation would include speech interference; operators would probably avoid communication at this time, much the same as the operator of a vacuum cleaner presently does. But, if the actual noise level falls in the upper levels of the estimated range, hearing damage risk cannot be dismissed. Although the average exposure to such levels would be limited to fractions of hours per week, certain elements of the population might be subject to prolonged exposure. For instance, apartment maintenance men could be exposed to several hours of this noise daily. Although this exposure would not constitute an imminent hazard to hearing, it could nonetheless hasten eventual hearing damage in the context of cummulative exposure from many sources. However, unlike other noisy appliances, the operator for the grinder need not remain in the same room when the machine is grinding. Sound insulation afforded by moving to an adjacent room would reduce noise to acceptable levels.

Sleep interference would probably be minimal. In the household, operation times of the appliance could be arranged to avoid conflict with times persons are usually asleep. Due to service area or basement placement, noise levels from the grinder in bedrooms would probably be negligible.

Annoyance is probably the most significant of any indirect consequences. Operator annoyance is usually not as severe as annoyance to persons to whom the noise is intrusive. In single family homes, this effect is deemed slight since family members will have control over when the appliance is used. And as mentioned previously, frustration may not occur when the ability to stop or reduce intrusive noises is possible. Neighbors outside the single family home would not be exposed to significant noise levels due to shielding effects of the structure.

Noise standards for appliances are currently only a function of market place pressures. A survey of appliance manufacturers by the EPA showed that with the exception of air conditioners, there is little customer pressure for quieter appliances.[69] Indeed, sales of machines such as vacuum cleaners show strong demand for noisier machines; perhaps the American public equates power with noise.

In spite of the weakness of market pressure, many manufacturers do have research and development projects aimed at noise reduction. Most felt further reduction was possible with present technology, but that a 5 - 20 percent cost increase would be the penalty for quieter appliances.[70] It thus seems reasonable to conclude that noise from the refuse grinder, while noticeable, may not be serious. Provided they are of short duration, high noise levels are accepted by householders, and are not regarded as health hazards.

Public Health and Visual-Aesthetic Considerations

The impact of refuse collection practices on public health and on the visual-aesthetic environment are closely related, being both largely dependent on refuse storage methods preceding collection, and hence a simultaneous consideration of both elements is indicated. A wet systems implementation would largely eliminate the problems of storage of refuse awaiting collection, and a major beneficial impact on public health and the visual-aesthetic quality of the environment can be expected.

Storage Facilities. One study indicates that at least among low-income families, areas of multi-family dwellings may contribute less waste per capita than families in less dense, single-family structures,[71] and thus storage space required for each household may be greater in single-family neighborhoods. This will be offset to a large degree by the greater availability of places to store refuse in these areas. The typical occupant of a single-family detached home stores his refuse in trash cans, barrels, or bags. These are commonly placed outside the dwelling in a spot out of view such as the back or side of the structure. In row houses and apartment buildings, a central deposit area or receptacle is often provided. Location may vary from outside a parking lot to indoors in the basement of the building.

For both single-family and multi-unit dwellings, storage locations can influence visual-aesthetic and public health impact. Outside storage relies on the refuse receptacle itself to hide the refuse, keep it from pests, and prevent litter and odor. An inside location, whether inside the dwelling, in the basement for example, or enclosed in an outside location, could compensate for inadequate containers. It should be noted, however, that insect and rodent vectors may not be impeded by any but the most secure enclosure.

Observations in the Study Area. Although Springfield has adequate legislation to ensure proper refuse disposal, the ordinance is rarely enforced. The vast majority of containers placed on the curbside were inadequate in one or more of the four categories mentioned above. Predictably, these inadequacies were most notable in the poorer sections of the city, but present to a lesser degree in all sections.

In all but the most well-to-do suburban sections of the city, the majority of rubbish containers were not the standard 30-gallon galvanized trash cans with lids. Prevalent in numbers were plastic trash bags followed by galvanized 30-gallon cans without lids, then industrial metal drums of 50-55 gallon capacity, corrugated cardboard boxes, paper supermarket bags, pressed cardboard drums of 40-60 gallon capacity and finally standard 30 gallon cans with lids. No wet-strength paper bags made especially for refuse were observed.

The most popular storage methods in low income and redeveloped areas of the city observed are plastic bags, large metal and cardboard drums, paper supermarket bags and corrugated cardboard boxes, in that order. The plastic bag, often lauded for saving collectors' time, we found to be frequently misused. The abuses include stuffing the bag so full it tears, not tying the bag closed, and placing articles in the bag which puncture and tear the bag. These abuses, when they occur, render the bag useless in preventing litter, odor, pest breeding and feeding. The plastic bag properly used should be stored in a rodent and dog-free area since these creatures can easily make the food inside available by tearing the plastic. The plastic bag may retard animals somewhat by retaining odors which let the animals know food is near. However, bags stored habitually in the same place may not even be effective in this.

The large drums were found to have several disadvantages. They are not manufactured for rubbish and so have no lids, making their contents available to rodents, flies, and dogs. Litter is generated from these cans in another way. The cans are so large and often so heavy that they are tipped on their side and rolled by the collectors from curbside to the packer. This tipping often results in refuse being spilled out of the top of the drum since the drums are packed full to overflowing. The collectors seem to resent these drums and may not bother to pickup this spillage. As an alternate to tipping, the drums are often dragged to the truck. The cardboard containers develop holes in their bottoms from this, and are also susceptible to wetness from rain and wet garbage. The other two containers common in the low income areas, paper supermarket bags and cardboard boxes, are obviously deficient in all areas. Additionally, when wet from rain or garbage, these bags and boxes often rip when picked up, depositing their contents on the roadway or alley.

It is interesting that our survey teams noticed that the care taken in packaging the refuse at curbside was reflected in the care taken by the collectors in loading the refuse and in cleaning up spills and litter. Consequently, in areas where inadequate containers cause spills, where rubbish and garbage is dripped through wet paper sacks, torn bags, and tipped drums, collection crews are likely to leave the mess right where it falls. On spills which were their own fault, the collectors were usually diligent in cleaning up their mistakes.

The above phenomena may have a correlation with individual pride. In the single family neighborhood, more space is available for placement of refuse for pickup. A messy, untidy pile of rubbish is identified with the home owner. In multi-dwelling units where less space is present, unsightly communal storage areas do not reflect as directly on an individual occupant, hence the individual's sense of responsibility is absent.[72]

Cross Connections. Perhaps the most serious potential public health impact, and the one that would certainly attract close attention from public health authorities, is the possibility of a faulty cross connection in the grinder.[73] This possibility exists because of the need to provide fresh water for the flushing cycle that must follow grinding.[74] Cross connections are a recognized public health hazard, and major epidemics of water borne diseases in the developed countries almost invariably follow the incursion of wastewater into the water distribution system via some form of cross connection.

However, it could be argued that the stringent laws and regulations concerning cross connections were developed of necessity in a time when water and wastewater systems were introduced to urban areas haphazardly, and without adequate supervision. But if the grinder is designed in such a way as to inherently avoid possible hazards, the anticipated fears of the public health authorities might well be allayed. The engineering principles of cross connection control are well understood,[75] and no insurmountable difficulties are anticipated in adhering to these in the design of refuse grinders.

Impact on Rodent Control. As all putrescible components of refuse would be quickly disposed of through the grinder, no burden is placed on the householder to safeguard the refuse or garbage against vector infestation. Refuse would, in the storage and collection phases, virtually be eliminated as a source of food for rodents and insects, with the possible exception of rodent populations in the sewers. It is conceivable that the rodent problem in sewers might be increased if more food in the form of ground garbage and food waste were delivered to the sewers. Evidence has been offered to support the fact that a high density of garbage grinders in a community may be associated with increased rodent populations.[76] This relationship is uncertain, however, because rodents commonly reside in sewers, even when food sources are on the outside. In the study area, serious rat problems occur in areas of combined storm and sanitary sewers, rather than in the areas where garbage grinders are prevalent. Indeed, there is evidence that domestic sewage without ground refuse may be capable of supporting rat populations. The Building Research Advisory Board of the National Academy of Sciences feels that grinding garbage for disposal to sewers offers a net benefit to control of a community's rat population.[77] And since it is known that shredded raw refuse in landfills is not suitable for rodent consumption, one can only surmize that mixed refuse suspended in water would be even less suitable.

The elimination of curbside refuse storage has some further unexpected and beneficial consequences. For example, a recent study linked urban stray dogs to the urban solid waste problem[78] and established the free-running urban dog as a part of the cycle of urban waste, litter, and disease. It was found that the dogs may exist in a symbiotic relationship with urban rats. The dogs often assist the rats unknowingly by tearing bags and spilling trash cans in their own search for food, and were observed feeding on refuse side by side with rats. To the extent that this food source would be eliminated, a wet systems implementation might play a substantial role in the control of the stray dog population, a problem that is becoming to be recognized as very serious.

Water Quality

The impact of a wet systems implementation on water quality in the Springfield area must be put in the context of existing shortcomings in water quality management in the region. Three areas are currently of concern; the landfill at Bondi Island, the discharge of stormwater overflows into the Connecticut, and the inadequacies of the existing primary wastewater treatment facility. Only in the last area are current plans sufficient, and the new planned secondary treatment facility is about to enter construction.

The refuse disposal site currently used in the study area is regarded by many as a threat to surface and groundwater supplies. Located on Bondi Island in the town of Agawam, Massachusetts, adjacent to the Westfield and Connecticut Rivers, most of the site is a flood plain that includes a post-glacial oxbow pond. But recommendations to close this facility must be put in the light of the realities of the fragmented New England governmental structure, and the exceptional difficulty of finding politically acceptable sites.

In Springfield, combined sewers still serve the downtown and surrounding older sections of the city while newer suburbs have separate systems. The impact of stormwater overflows on the water quality of the Connecticut River below Springfield is substantial. Presently, a two month frequency storm of 30 minutes duration results in the carrying of 10 tons of BOD into the river.[79] Significant reduction of dissolved oxygen levels in the river results, although the depletion is not sufficient to violate the Massachusetts C water classification of the Connecticut. Present plans to alleviate this situation were outlined in Section VII, above.

Impact of Wet Systems on Water Quality. Although recognizing the limitations of the computer model and its results as discussed in Section VII, we would not anticipate any difficulty in meeting the same effluent quality with ground refuse as will be the case for the new planned facility treating just wastewater, and the water quality of the Connecticut River, as measured by conventional parameters, would not be compromised. Indeed, to the extent that the Bondi Island landfill site, which might be unsatisfactory from a water quality viewpoint, would be used for landfilling of a stabilized digested sludge containing no free moisture rather than for filling of raw refuse, the net impact on water quality would be positive.

With regard to the combined sewer overflows, we have already noted that the implementation of a wet system in Springfield would be contingent on a prior or simultaneous separation of combined sewers. But since we anticipate that grinders would first be installed in the relatively affluent suburbs,[80] all that would need replacement initially are any combined intercepters that carry wastewater from outlying areas through the central areas where combined sewers are prevalent. This would avoid any additional stormwater loads on the Connecticut River resulting from ground refuse additions.

Need for Revised Effluent Standards. In view of the rather limited information on the possible quality of effluents from wastewater treatment facilities handling ground refuse, the need for revised effluent standards is difficult to ascertain. Metcalf & Eddy's experiments do show, however, that the COD of a conventional secondary effluent would be substantially higher than present levels, due mainly to fine cellulose fibers in suspension. A standard for COD would therefore be indicated for such facilities, although establishment of the permissible levels would need further bench and pilot scale studies. As indicated by our computer model results, there appears to be little difficulty in meeting existing effluent quality limitations for BOD, suspended solids, dissolved nutrients or other parameters commonly in use for sewage treatment effluents.

Socioeconomic Impacts

The prediction of socioeconomic impacts, and in particular predictions in quantitative terms, is a difficult and complex task. Two chapters in the case study report address these impacts at some length,* to which the reader is referred for further detail, and we shall here summarize only the more important points. A detailed econometric analysis of refuse generation in the Springfield SMSA was also conducted as part of this study with a view to identifying socioeconomic factors affecting spatial and seasonal variations in generation rates. The results of this analysis are reported separately in a technical paper. (See Section XIII.)

Impact on Private Capital. A shift from conventional handling to wet systems would reduce the scope of both private industry and municipal activity in refuse collection and disposal, and increase municipal activity in sewerage. If the shift were to be widespread, it would replace some frequent private house-to-house collection in sewered areas, leaving only occasional collection of nongrindables. Thus, some investment opportunities will be lost to private enterprise. But as any shift seems bound to be very gradual, and as the total private capital is small relative to the national economy or to any particular metropolitan area, the effect will hardly be noticeable in the aggregate in any one year. Our conclusion here is more optimistic than in the case of labor (see later discussion), because the owners of capital are undoubtedly more capable, on the average, of adjusting to the decline. They can turn their talents and money elsewhere. A very important factor in smoothing the adjustment is the market for used equipment. There is national advertising of used equipment, and it can be transferred to other geographical areas at a cost which is small relative to its value (a ten-year old collection vehicle might still sell for $3,000 to $4,000 in the second hand market). Used equipment is bought and sold by private operators, municipalities, new equipment dealers, and firms specializing in reconditioning and refitting older vehicles.[81] There will still be need for landfills, and the general scarcity should prevent serious decline in value. Naturally, there may be some difficult adjustments and permanently adverse consequences on a few entrepreneurs, but neither the waste of capital, nor the losses to individuals, should be serious enough to count for much in the aggregate picture.

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*Meier, Kuhner and Bolton, (Ref. 22), Chapters VII and VIII.

Unemployment. As the primary cost-reducing effect of wet systems is in the elimination of labor in conventional collection, the unemployment problem naturally comes to mind. Indeed, pressure from workers and unions to avoid reductions in municipal forces, and public sympathy for unemployed workers, will be an important barrier to adoption of wet systems. It might be especially strong in a city like Springfield, which is in a labor market area which has had unemployment well above the national average in many years. In April and May 1973, for example, the unemployment rate in the Springfield-Chicopee-Holyoke labor market area was 6.8 percent (in June the flood of students looking for jobs raised it to 8.2 percent, but that was a seasonal increase). The average monthly rates were 8.5 percent in 1971 and 7.9 percent in 1972.[82]

The concern with unemployment is entirely valid in principle. However, we feel it is not a very important consideration in the present context. Any adoption of wet systems should come gradually, and some of the workers laid off in refuse operations will find jobs in the sewerage operation of the same city, or in other public works departments. The small number of workers laid off in any given year would easily be absorbed elsewhere as normal attrition opened up new vacancies. It should be stressed that the case will not be one of massive layoffs, as have occurred or been threatened in cities where refuse collection has been drastically altered overnight, such as by eliminating backyard collection, or by reducing the frequency of collection, and resulted in drastic reduction in crews.

There are about 225,000 workers in the labor force in Springfield's labor market area, and the few workers who would be released outright, not having been transferred to other jobs in the city, would have an almost negligible effect on the total picture. Even a fairly rapid changeover to wet systems by Springfield would take 5 to 10 years, and the number of workers released outright could be as low as 20 per year. Furthermore, refuse work requires no special skill or experience, so the workers will not suddenly find themselves with obsolete human capital which they have built up at cost to themselves. Obviously, the city would find it desirable to smooth the workers' transition to new jobs, perhaps with special unemployment payments and certainly by careful phasing in of new methods. The point is that such extra costs would be very small and should not be a significant barrier to the new method.

Impact on Municipal Finance. On the municipal side, the net financial impact is to decrease expenditures out of current income and to increase expenditures financed by borrowing. The net effect of this depends on the monetary cost comparisons between the two alternative methods - counting only the monetary cost to the local government. This depends on the total monetary cost comparisons in the economy as a whole and on the shares of the costs which local governments must pay, and also on whether waste reclamation brings net profits to municipalities.

A very important factor will be state and federal policy on grants for sewerage facilities construction, which, unfortunately is very difficult to predict. The question is whether such grants will be as liberal when facilities handle solid waste. On the one hand, there is a long tradition of sewerage grants, and the federal stance was reaffirmed in the 1972 legislation which mandated higher standards to be achieved. On the other hand, this tradition has been essentially lacking in solid waste. This is not an arbitrary distinction; the principle has been that sewerage aid was needed to prevent pollution of environmental resources, which benefitted numbers of people far greater than the population of a single town or city. This principle is much less applicable to solid waste, although not totally irrelevant there. Especially the federal government would find it hard to justify aid for facilities to handle solid waste, although it has a clear role in research, demonstration, regulation of packaging, incentives for reclamation, etc.

Whatever the federal and state governments decide to do will be crucial for whether wet systems are introduced extensively. For many areas, the total costs of the two alternatives are bound to be closely matched, and even a small change in the percentage of cost defrayed by grant will tip the scales. This is not to deny that wet systems will sooner or later make some headway in some areas even without any grants to cover the added sewerage costs, or that even extensive grants will not be sufficient in some other areas.

There is another aspect of grants policy which bears mention. All federal sewerage grants are now being made conditional on the municipality levying user charges, which distribute costs to users in proportion to their loads on the system, and sufficient to cover all operation and maintenance (including replacement of components) costs. Some municipalities will have to increase user charges over what they would want to charge in the absence of needing the grant, others will have to institute sewer charges for the first time. This will accentuate the difference between conventional handling and sewage treatment in the relative reliance on user charges, to which we now turn.

It is not inevitable that conventional methods be financed more by taxes than user charges. Nor would wet systems automatically result in more reliance on user charges. The technical nature of handling does not dictate financing; we note for example the great variation from city to city in the use of charges in both solid waste and sewerage. However, it seems appropriate to compare the two systems taking as given the present differences in financing of government costs, as shown by the national averages.

The picture is clouded, however, by the heavy subsidy from state and local governments in sewerage. Do we measure reliance on charges by their proportion of private costs plus municipal costs, or their proportion of total national costs? The second proportion is much lower. The present subsidy is composed of two parts. The first is the federal tax treatment of municipal interest, which applies to all local capital expenditures financed by borrowing, sewerage among others. The second is the construction grant, which is tied to sewerage *per se*. The first part might be justified on very general grounds--it is essentially a form of revenue sharing. The second part might be justified by considering rivers and lakes as national resources, and assuming localities deserve to be offered heavy subsidies for avoiding polluting those resources. The subsidy does not now seem to be offered as an *incentive* to avoid pollution, because recent legislation has moved toward prohibiting that in any event.

The first part of the subsidy would continue to operate if sewage treatment plants were enlarged to handle refuse--the extra capital cost would be covered by borrowing at the same interest rates as on other municipal borrowing. We shall assume here that the second part would *not* be extended to cover such extra capital costs, that is, we assume that localities will have to finance the extra costs of handling solid waste on their own. This is a reasonable assumption given the histories of federal policies on sewerage and solid waste, and the already high grants projected for sanitary sewerage alone. We also assume that grinding costs will not be subsidized, certainly not by state and federal governments. All these assumptions imply that there definitely will be more reliance on user charges in wet systems than there is at present, resulting in an improvement in efficiency.

One important characteristic of wet systems is that the transactions costs of using the price system are much lower in wet systems than under conventional methods, if the load on the sewerage system can continue to be fairly well measured by water flow. Presently, water flow is commonly assumed to be an equitable proxy for sanitary sewerage costs. It is widely used to determine sewerage charges, and is expressly permitted in the new federal regulations on acceptable charge schemes for facilities aided by construction grants.[83] If some households have grinders and others do not, water flow-based charges can be used for all households, but the level of rates would be higher for those with grinders (their charges for conventional collection would be lower, of course).

Water use is already measured for many households and the additional clerical and administrative costs (and complaints) would be very low. If water is not already metered, the advantages of simultaneously measuring water usage, liquid waste loads, and solid waste loads would justify the expense of introducing metering, for the transactions costs would contribute to efficiency and equity for several public services and a much larger block of scarce resources.

Water use is certainly not a perfect measure of waste loads under wet systems. But a charge based on water use would be preferable to no charge at all or a charge completely unrelated to waste flows. The goal in cost assessment cannot be perfection, for the transactions costs are too high for that; it is merely to strike a balance which improves efficiency and equity without using too many resources in measuring and billing. The scope for this seems considerably greater for the wet system approach than for conventional management. (More research is needed to determine the accuracy of water flow as a measure of sewerage costs under wet systems. Some of the research suggested in Section XI would also accomplish this result.)

A by-product of wet systems and user charges would seem to be improvement in efficiency of use for water in other purposes than grinding, for the amount of money spent on water by a typical household would be more noticeable than at present and make it worthwhile to economize on its use.

Income Distribution Effects. The change toward user charges identified above will have an extremely small effect on income distribution. User charges will replace taxes, and the net effect will depend on the relationship between income and collection costs on one hand, and between income and tax burdens on the other. Neither relationship can be specified precisely. Under the most plausible assumptions, the change would probably cause some extremely small change toward more inequality if all families had grinders and user charges replaced taxes in financing municipal costs. However, if adoption came about voluntarily, lower income families would not necessarily be absolutely worse off. If only upper income families adopted grinders, and paid higher user charges, the effect would be less inequality, because the higher user charges would replace some taxes paid by lower income groups. But whatever the effect may in fact be, its magnitude is likely to be quite insignificant.

Collective Bargaining. Various aspects of collective bargaining offset the choice between conventional systems and alternative systems. Labor relations are relatively very important in conventional collection, because the function is inherently labor intensive and is also important enough for public health and general amenity that disruptions due to labor disputes are very costly. Strikes in some functions have little more effect than to delay production of useful output for a time. The only cost is from the change in time of availability of a product, and that cost may be minor. In refuse collection, however, as in some other public services, even relatively short delays can have serious consequences. Disruptions in sewerage could also be costly, but the system is more mechanized and depends much less on constant, massive labor inputs; this would still be true even if sewerage were expanded to carry and treat solid waste. A work stoppage in sewerage, although possibly costly if treatment must be partially cut back, is less likely to cause a public emergency than a refuse collection stoppage.

The nature of the occupation and the vulnerability of the city to work stoppages contribute to union activity and use of strikes or threats of strikes as means of winning higher wages in refuse collection. Refuse collection is no different in this from many other activities in the economy. However, for a long time, legal prohibitions and public opinion inhibited unionization and strikes among public employees. More recently, some of the legal barriers have been falling.

In 1940, Ziskind[84] could already note that strikes by refuse collectors were especially common relative to other government employees: "The removers of refuse, the pariahs of the municipal personnel, have manifested a group consciousness and a maturity of strike techniques that have surpassed by far the protective efforts of the higher paid municipal employees." While he listed refuse collection strikes in 26 cities, Ziskind devoted most attention to their history in New York and Chicago. In 1907 and 1911 in New York, strikes of several days duration were broken by the importation of strike breakers, which occasioned violence. In the 1920's and 1930's, there were seven strikes in Chicago, some several days long, over a variety of issues, such as the attempt of the depression-plagued city to reduce forces or hours and its failure to pay full wages, disputes over rights to jobs in return for political activity (for instance, in 1933, "a spectacular struggle between politicians and trade-union bosses," p. 89), and control of employment at private disposal sites where the city dumped its refuse.

Ziskind also commented on strikes of sewerage workers, contrasting their near-negligible effect on the public with the effect of refuse workers: "The strikes have...never seriously interfered with the normal functioning of existing sewer systems," although they may have retarded the extension or improvement of a system (p. 95).

Over the 1960's, the number of strikes in refuse collection, and man-days idle in strikes, increased greatly, along with other strikes by other government employees. Refuse collection has continued to be one of the government functions most plagued by strikes, although it comes nowhere close to the schools in that respect.[85] Both the costs of strikes and the time, energy and resources expended in collective bargaining must be considered costs of conventional methods of solid waste handling, and costs which will grow as unionization increases employee awareness of wage parity; employees in one function make demands with a view to what others are demanding or have already won at the bargaining table.[86] The unionization of a function for the first time thus has a true marginal effect greater than indicated by the resources devoted to bargaining in that function alone. Another aspect is the predominance of black labor in some municipal collection forces. Some labor disputes have been aggravated by more general civil rights grievances. And it is not only wage negotiations which absorb time and energy; negotiations over working conditions are also costly, in time and possibly in inefficient practices.[87,88]

All of these factors may make alternative methods appear attractive to many. But one must not forget that alternatives which reduce the scope for labor disputes may have the inevitable consequences of altering the balance of political power in a city, consequences which are impossible to evaluate on economic criteria alone. The true significance of public employee unionism may be as much political as economic. It offers some group (public employees or blacks) the chance to increase their political power. One therefore cannot unequivocally say that an alternative like wet systems would be superior.

Wellington and Winter note that the costs of collective bargaining are less severe when public functions, including refuse collection, are performed by private firms, even if the firms' employees are unionized.[89] There may be times when economic and political forces encourage near-general strikes by all public employees, although such have been rare in fact. Public refuse collection may be stopped even when the collective bargaining issues are less relevant in refuse collection than in some other functions. Also, private employers may resist union demands more than public employers, because they are better organized and have more experience in bargaining, and because the latter are more open to political pressure to yield. Governments are organized in ways (division of powers, checks and balances) which make it difficult to present a united front. Even if a city government is forced to intervene in a strike of a private firm, the government is a neutral intervenor and not a direct adversary of the union. The authors also argue that a private employer can offer a more credible threat of unemployment as a result of higher wages - he is better able to substitute capital for labor and is more likely to raise prices to cover higher costs and thus permit a slower growth in demand. And governments seem more able to pass on higher costs to other levels of government, or to hide the increased cost in a complex and little understood budget. For these reasons, a government is more likely to meet a strike with a higher settlement, and thus to be struck in the first place.[90] The authors thus conclude that whether a particular function is appropriate for government now depends in part on the growth of public employee unionism, and they note refuse collection is one example where the choice between public performance and private firms depends partly on unionization. Similarly, the relevance of unionization for conventional handling depends somewhat on whether it is performed by public agencies or not.

All this may be true, but it remains ambiguous how to value these factors. While administrative costs and wages may be kept lower when private firms perform the function, employees are deprived of an avenue of economic power. This consideration may be important in assessing conventional methods versus alternatives. The wet systems method certainly inherently offers municipal workers somewhat less scope for exercising political and economic power. We can say, however, that the total numbers of workers affected by this would be small relative to the total of municipal employees, even if large scale changes were affected. Because any adoption of wet systems is likely to be gradual, the quantitative significance of loss of power will be even less.

SECTION X

TOTAL SYSTEM COST COMPARISONS

Economic Feasibility

The estimated total system costs, on an annual per household basis, for both the wet system and a continuation of existing conventional practice are shown on Table 11. The 1988 costs, which are shown in terms of 1973 dollars, have been derived on the basis discussed in Chapter VIII, utilizing a two percent annual increase in labor costs. A comparison of the system totals is even more unfavorable to the wet system than the generalized comparisons of Phase I (where the 1973 figures were estimated at $125-$182 for the wet system as against $43-$101 for conventional practice). Evidently, conventional waste management practices in Springfield are very efficient, with per household costs at the very bottom of the national spectrum.

But it should be reiterated that the $80-$105 annual cost of grinding is that for the Foster-Miller or Nebiker-Meier grinding concepts, both of which were rejected on the basis of excessive cost. Moreover, this is an annualized cost, which, again as noted previously, is not the basis upon which individuals would base a decision on grinder purchase. Consequently, the totals inclusive of grinding do not appear very useful.

If the cost of grinding is excluded, on the assumption that grinding costs would be borne by the householder, then the remaining costs are those to just the public sector, and these are considerably more favorable to the wet system, possibly 10 to 15 percent lower than conventional by 1988. Because this margin is rather small, the conclusion would be that implementation of the wet systems concept is still very distant. Yet on the other hand, if our prediction of potential consumer acceptance is correct, implying heavy involvement of the private sector appliance industry in developing and marketing refuse grinders, then it behoves the public sector to examine the consequences on its waste management systems, as it might otherwise be faced with the necessity of banning refuse grinders.

Other than the grinding cost component, most of the uncertainty in the wet system cost is attributable to the cost of sewer maintenance. As explained in Section VI, it is simply not yet possible to determine the necessary flushing frequency; yet it is the flushing frequency that primarily determines sewer maintenance costs. If flushing is necessary four times rather than only once per year, then the $6-$9 range assumed in Table 11 for 1973 would rise to $24-$36.

A problem perhaps inadequately addressed in the economic analysis is that of transition costs, i.e., the costs during that period when both conventional systems and wet systems coexist. The cost items for sewage treatment, sewer maintenance and grinding might be assumed to rise linearly with increasing number of installed grinders; however, it is unclear

Table 11: Total Annual System Cost per Household Comparisons for Springfield

	1973		1988	
	Conventional	Wet System	Conventional	Wet System
Refuse Collection	$17.50	-	$21.50	-
Collection of Nongrindables	-	$2.50	-	$4.00
Bulky Refuse Collection	1.00	2.00	1.50	3.00
Disposal	3.50	1.00	4.50	1.50
Sewer Maintenance	2.00	6.00-9.00	3.75	7.50-11.00
Grinding	-	80-105	-	80-105
Treatment	9.00	12.50	10.00	14.00
Sludge Handling	5.50	8.50	6.00	10.00
Sludge Disposal	0.75	2.00	1.00	2.50
Total	$39.25	$114.50-142.50	$48.25	$122.50-151.00
Total to Public Sector (Excluding Grinder)	$39.25	$ 34.50-37.50	$48.25	$ 42.50-46.00

whether the cost items for collection and disposal would also decrease linearly, and thus the possibility of a higher than expected transitional cost cannot be discounted. It may therefore be only at the point of complete implementation of the wet system that the expected wet system costs are attained. But until such time as the necessary detailed data on refuse characteristics becomes available, data that was unavailable to us, any attempt at quantifying the transition would be excessively speculative. This is not, however, to deny the importance of the problem.

Conclusion

Having shown the economics of the wet system to be somewhat unfavorable over existing and alternative concepts, having raised serious questions as to its technical feasibility, but also having shown some significant (even if unquantifiable) environmental and socioeconomic benefits, what, then, is our final judgment at the conclusion of our investigation?

Unfortunately, the complexity of the concept and its place within the many interlinked efforts at rational environmental management make any definitive pronouncement on the concept at the present time a very dangerous undertaking. The major reason for our reluctance to express absolute conclusions is the limited information on the technical aspects of the concept that is to date available. Taken at face value, the results of the economic analysis presented in these pages is indeed unfavorable to the wet systems concept, showing approximately a doubling of total per household cost for all the elements of domestic waste management. Yet at the same time, we have shown that if the cost of the grinder is borne by the householder, there may be situations where the cost of the wet systems concept to the public sector may be less than any conceivable improvement of today's concepts. Thus, given the premise of technical feasibility, we arrive at the conclusion that its economic feasibility, by which we mean that cost is no greater than that of its competitive alternatives, rests upon the willingness of householders to purchase a grinder for benefits of convenience and aesthetic or environmental improvement of their homes. Such a premise is not to be dismissed lightly, given the indications of continuing increases in disposable income. And skeptics might be reminded of the realities of the current market for trash compactors, an appliance that surely offers fewer convenience benefits than refuse grinders.

Certainly we may conclude that demonstration scale research investments are as yet unwarranted. At the same time, however, we believe that a limited program of further studies directed specifically at the resolution of a few key technological uncertainties would allow judgments that are based on more substantial evidence than the largely circumstantial inferences that are available to us at the present time. If these further studies, as elaborated in the following section, have favorable results, then we believe that the wet systems concept would gain consumer acceptance to the point where implementation became feasible. This is contingent, however, not only on a confirmation of technical feasibility, but on the availability of a grinder whose cost is compatible with consumer acceptance.

SECTION XI

RECOMMENDATIONS FOR FURTHER RESEARCH

Our investigation has pinpointed several areas of technical uncertainty, and consequently definitive judgment on the technical feasibility of the ideal are made only with great difficulty at this time. However, it has been possible to analyse these uncertainties to the point where a program of a few selected, but pertinent, investigations could resolve these unanswered questions, and to this end we have set forth a program of research tasks. The sequence of tasks is ordered in such a way that the most critical questions be addressed first, and so that further investments may be terminated if the results of the most critical investigations are negative.

Because these unresolved technical questions are quite substantial, we feel that investment of research monies as the next step, at the level required for demonstration scale project would be premature, and a decision on such investments should be preceded by the program of laboratory scale studies herein described. A detailed analysis of the quality parameters and conventional treatibility of ground refuse-sewage mixtures may be regarded as a first priority, and is already under consideration as an in-house study at the EPA National Environmental Research Center in Cincinnati. The information yielded by this study will considerably extend the existing knowledge on the subject developed by the Metcalf and Eddy investigations, and will allow much more reliable estimates to be made for the likely cost of treatment. There remain to be addressed, however, the following series of tasks, presented in the recommended sequence. Note that Task 5 is probably the most costly, and should therefore be undertaken after the other, relatively cheaper, tasks.

Task 1: Hydraulic Studies Under Unsteady Flow Conditions. The most important known limitation to the technical feasibility of the wet systems concept concerns the ability of an existing gravity sewer system to transport ground refuse. The results of the Springfield case study show very clearly that in many sewer laterals, the scour velocities required to prevent excessive deposition of the glass and ceramic component are rarely present, if indeed at all. Moreover, it remains questionable whether the generally optimistic conclusions of the Foster-Miller studies, which would appear to show few problems to occur under steady-state conditions, are at all valid for the unsteady flow conditions actually encountered in most parts of a gravity sewer system, and in particular, in the laterals at the periphery of the system.

In order to resolve these problems, a study of hydraulic transport of ground refuse in a simulated system of sewer laterals is proposed, with the objective of extending the findings of the existing Foster-Miller studies to unsteady flow and solids load conditions. The experiments should be conducted in a test loop of eight-inch glass sewer several hundred feet long, and with a representative selection of appurtenances.

The injection of ground refuse should be through simulated building connections spaced at appropriate intervals along the test loop, and discharges timed to simulate as closely as possible real conditions. The ground refuse injected should include the glass fraction, and the experiments run over at least weekly cycles in order that quantitative judgments on accumulation problems can be substantiated. Although it is recognized that such a simulation program may involve substantial effort and considerable sophistication in laboratory procedures, anything less would not yield information that will provide conclusive evidence on the feasibility of hydraulic transport in real systems.

Task 2: Field Survey of Refuse Generation and Water Consumption. The case study was unable to fully answer the questions of the feasibility of refuse grinding and sewer transport because of certain data inadequacies. In particular, no data is available on the refuse generation, water consumption and sewage production of single households. The use of average values for groups of households may be dangerous if the degree of correlation between these three variables is unknown. If in fact households with high refuse generation also generate high sewage quantities, the problem of adequate grinding water will be less acute than is suggested by use of average values. Unfortunately, knowledge of this correlation is crucial to a judgment of feasibility, and, therefore a field investigation to rectify this deficiency is proposed. This field survey would involve the selection of a series of representative refuse collection truck routes in the study area, and sample a series of households on this route for water consumption and refuse generation. The program might include:

> Weekly readings of water meters on the day of refuse collection. Water meters can generally be read without requiring access to the interior of a dwelling unit, thus involving no inconvenience to householders.
>
> Curbside weighing of refuse containers on the day of collection prior to pick-up by the collection crews. This sampling might be conducted half an hour ahead of the collection, involving no impediment to the collection crews. Portable scales mounted on a suitable push-cart would be adequate for this purpose. By sampling only a portion of the households on each route, the sampling crew could operate at the same speed as the collection crews, thus preserving a constant difference between the two operations. A certain number of samples could be collected in plastic bags for subsequent composition analysis and determination of which components could not be ground by virtue of their bulk.
>
> Determination of the maximum flow depth (and hence velocity) of the sewage flow at manholes along the sample routes.
>
> Continuous monitoring of sewage flows in a selection of residences.

Statistical analysis and interpretation of all data collected.

Because of strong seasonal variations, this study should be conducted over a 52 week period. It is, however, probably unnecessary to sample all households every week; once every four weeks would be sufficient for all but a few sample households.

Only data collected at this level of detail will allow meaningful conclusions on the feasibility of refuse grinding and the development of adequate grinder specifications. Ideally, this task should run concurrently and be closely coordinated with Task 1, and be conducted in the same Springfield case study area as used by this investigation.

Task 3: Energy Balance Studies. In the 18 months that have elapsed since the start of this wet systems evaluation, national energy shortages have reached major proportions. An evaluation of any radical innovation, such as the wet systems concept, must therefore include examination of the impact of its implementation on energy consumption, but unfortunately could not be included as part of this study for reasons of time and resources. A focus on energy consumption is especially important in view of the energy market distortions resulting from government controls. Energy costs, and total systems costs, may thus not necessarily be an adequate indicator of the true social costs of the various alternatives.

(At first glance, the trade-off appears to be savings in fuel for collection vehicles as opposed to increased electricity use for grinding and treatment plant operations. However, to the extent that anaerobic digestion and its methane by-product could satisfy a substantial portion of treatment facility power requirements, the net impact of a wet system on energy consumption would probably be positive.)

Task 4: Evaluation of Potentially Hazardous Components in Refuse-Sewage Mixtures. Phase I of this investigation established the possibility of potential problems arising from the addition of potentially hazardous materials to the treatment plant. But because there is no actual evidence, only indirect estimates that are inconclusive, it is recommended that a series of laboratory investigations provide some facts on this question. Advanced instrumentation analyses of simulated treatment plant inflows and secondary effluents should provide the necessary evidence of higher (or lower) concentrations of specific materials (pesticides, herbicides, toxic heavy metals) resulting from the addition of ground refuse. Such evidence would further allow appropriate additional advanced waste treatment processes (or changes needed to already existing processes) to be identified with some degree of confidence and thus make estimates of treatment cost in the presence of ground refuse more credible than those that can presently be made.

Task 5: Development of Alternative Grinding Concepts. The results of our investigations show clearly that existing grinding concepts envisaged for wet systems are unlikely to be implemented for economic reasons. Replumbing of existing housing as would be necessary under the Foster-Miller concept is prohibitively expensive and must be regarded as infeasible. On the other hand, grinding at high consistencies, as called for by the Nebiker-Meier concept, requires a pressurized building connection, the cost of which is also very high. Moreover, the question of how much grinding water is available, and what minimum solids concentrations are necessary to prevent deleterious effects in the sewer system under the unsteady flow conditions encountered in practice are obviously crucial to the development of grinder specifications. Consequently, additional effort in this area rests on the results of Tasks 1 and 2. Since the major cost of existing grinding concepts lies not in the grinder itself, but in ancillary arrangements, a successful grinding concept that would avoid these would have some chance of success in removing a major barrier to a wet systems implementation. One such alternative concept might involve grinding at high consistency, but discharging to the building connections only at such times when the flow from other domestic appurtenances, such as following toilet flushing or washing machine discharge, would provide adequate dilution water.

Task 5 should be divided into 3 phases. In Phase I, alternative concepts should be evaluated with the help of laboratory simulations that would examine the behavior of refuse slurries and their dilution and mixing with other domestic wastewaters. Phase II would develop an appropriate design which should be constructed and tested in a third phase. Any demonstration project would obviously depend on the availability of an already constructed and tested grinder.

Task 6: Comprehensive Reevaluation of the Concept. Completion of the previously specified Tasks 1 through 5, and the study shortly to be conducted by the EPA National Environmental Research Center in Cincinnati that will obtain further data on the quality parameters and conventional treatability of ground refuse-sewage mixtures, should allow an evaluation of the concept that is founded on much more concrete evidence than has been available to this study. This proposed reevaluation would be in a position to make a definitive judgment on the economic and technical feasibility of the concept, and, if found to be feasible, would have as a major goal the planning of a subsequent demonstration project. This reevaluation is felt to be very necessary prior to commencement of a demonstration program that would involve investments of a very much higher order of magnitude than the studies previously conducted.

SECTION XII

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89. Wellington and Winter, *op. cit.*, pp. 62-64.

90. *Ibid.*, pp. 195-196.

SECTION XIII

PUBLICATIONS

The following papers are in preparation for publication in technical journals. Some further papers are in the planning stages. At least one of these will be submitted to German and Swiss journals.

Bolton, R., "An Econometric Analysis of Household Refuse Generation," in preparation for submission to *J. of Environmental Economics and Management*.

Meier, P. and J. Kuhner, "Simulation Analysis of Wet Systems for Residential Refuse Collection," to be submitted for publication in the *J. Environmental Engineering Division*, ASCE.

Meier, P., P. Kos and J. M. Joyce, "The Treatment of Ground Refuse at Modified Sewage Treatment Facilities," to be submitted for publication in the *J. Water Pollution Control Federation*.

The following papers were presented or will be presented at technical conferences:

Meier, P., "Management Aspects of Refuse Bioconversion," presented to the National Science Foundation Bioconversion Energy Research Conference, University of Massachusetts, Amherst, Massachusetts, June 1973. (Published in the conference proceedings, p. 79-87; available from The Institute for Man and His Environment, University of Massachusetts, Amherst, Massachusetts 01002.)

Meier, P., "Wet Systems for Handling Solid Waste," to be presented at the annual meeting of A.I.Ch.E., Pittsburg, June 4, 1974.

The following technical reports were prepared in the course of the research project and are available from the National Technical Information Service, Springfield, Virginia 22151.

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